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PERSPECTIVES ON THE PROSUMER ROLE IN THE SUSTAINABLE ENERGY SYSTEM

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UNIL | Université de Lausanne

FACULTÉ DES HAUTES ÉTUDES COMMERCIALES

DÉPARTEMENT DES OPÉRATIONS

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THÈSE DE DOCTORAT

présentée à la

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de l'Université de Lausanne,
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I M P R I M A T U R

Sans se prononcer sur les opinions de l'autrice, la Faculté des Hautes Etudes Commerciales de l'Université de Lausanne autorise l'impression de la thèse de Madame Kirsi KOTILAINEN, titulaire d'un Master of Science in Industrial Engineering and Management de l'Université technologique de Tampere - Finlande, en vue de l'obtention du grade de docteure ès Sciences en systèmes d'information, en cotutelle avec l'Université de Tampere - Finlande.

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and have found it to meet the requirements for a doctoral thesis.
All revisions that I or committee members
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External member of the doctoral committee

PREFACE

It feels like forever ago when I started this process at the library of CERN (thank you CERN for that excellent working space!) in Geneva in January 2016 after a few years of enjoying motherhood, living in Switzerland and searching for my "next big thing". I knew that career wise, after having spent 17 years at Nokia Corporation, no matter how exciting and fulfilling those years had been, it was time to do something else, and preferably something that "mattered". Finally, I made the decision to start the PhD and learn about sustainability and renewable energy in order to one day perhaps change the world. Like always when embarking on a new adventure, little did I know then what a journey lied ahead. At first, I was curiously exploring the topic, learning new things (and also learning how to write full sentences after years of producing power point presentations), writing the first conference papers and familiarizing myself with the academic circles. Yes, the first couple of years of the PhD journey were fore mostly fun, creative and very fulfilling and I realized I really enjoy doing research. As the pressures to bring this work to an end gradually started to creep in, I have looked back to those early days to remind myself of why I started this journey in the first place. But here we are, finally, it's done! And most definitely this would not have happened without the support from so many others.

First of all, sincere thanks to all my supervisors at Tampere University and University of Lausanne! Leena-Aarikka-Stenroos, you came to be my supervisor at a later stage, but your support has been important. Thank you especially for all the practical and concrete advice that helped me finalize the dissertation. Pertti Järventausta, I have learned so much from you. Your deep knowledge about energy system and markets have been so valuable. Thank you for being a solid mentor to me during this journey. Petri Suomala, you were my first supervisor and it was a pleasure to get your calm guidance in the early stages of the journey. Thank you for taking me onboard and advising me. Ari-Pekka Hameri, thank you for your guidance at the University of Lausanne. I couldn't have finished, or even started, this joint-supervision degree if it weren't for you. It was a great opportunity to do this dissertation in two well-respected institutes.

I also sincerely extend my gratefulness to the two pre-examiners Eva Heiskanen and Johan Kask who invested their time to examine my work and gave constructive

feedback to improve the manuscript. Likewise, I want to thank the University of Lausanne doctoral jury members Martin Patel and Ann van Ackere for examing the dissertation and also giving highly valuable feedback. I likewise sincerely thank Jouni K. Juntunen from the Aalto University; our research interests are quite closely intervened and it is an honor to have you as my opponent.

A project like this is impossible without financial support. During my journey, I had a pleasure to work in two amazing projects, Prosumer centric energy ecosystem (ProCem), funded by Business Finland, and EL-TRAN, funded by Academy of Finland's Strategic research council. Thanks to all my colleagues from various departments at ProCem for that excellent multidisciplinary experience! Pami Aalto, at EL-TRAN, thank you for taking me onboard! You exposed the world of policies to an engineer and were open to the cross-disciplinary research that I was conducting. I truly learned a lot. I also received funding from Tampere University doctoral school and I would also like to thank the CITER group in Hervanta; it was nice to be part of such talented and energetic young research team. Furthermore, Fortum Foundation enabled the opportunity to visit the University of Cambridge at the Energy Policy Research Group (EPRG). Thank you, David Reiner and the whole EPRG team, including its many international visitors, for your kind guidance and for your understanding that my dissertation was distracting me from being able focus 100%. Then last year, while frantically trying to write the summary for the dissertation, I joined VTT Technical Research Centre of Finland where my learning about sustainability and energy has continued. Special thanks to Tuula Mäkinen and Juha Hämekoski for your support! And Sami Kazi, I'm grateful for your kind encouragement and advise on improving the manuscript.

One thing I have especially enjoyed, has been writing papers with amazing and professional researchers. I would like to thank my co-authors that contributed to the appended articles, especially those that I have not mentioned yet: Joni Markkula, Saku J. Mäkinen, Antti Rautiainen, Christian M. Ringle, Ulla A. Saari, Matti Sommarberg and Jussi Valta; it was a pleasure to work with you! Jussi, you receive a very special thanks for being a such a great peer support – and even presenting some of my papers in the conferences far, far away when I could not make it. In addition, I wrote multiple papers that did not end up being attached to this dissertation with my colleagues from ProCem, EL-TRAN and EPRG - I highly appreciate those experiences too!

Last, but not least, I want to thank my friends and family. And apologize as well. Towards the end this journey was a lonely one and took most of my time and energy. Dear friends, please forgive me for being so unsociable for too long, I miss you all!

My father Matti sadly passed away before I could finish. But I know he would have been proud. Thank you, father and mother, for making it possible for me to become whatever I wanted to be, you've always supported my decisions. Thanks also to my sister and brother, their families and everyone else in the family for putting up with my recent priorities.

Finally, thanks to Saku and Lumi! Saku, besides taking care of the things at the home base lately, you have given me tips and encouragement that have allowed me to move forward even the things looked a bit desperate at times. In the beginning, you told me to "just start writing" when I was in horror to have only a few weeks to write my first conference paper. I would not have started nor finished this project if it weren't for you. And thank you for my lovely, precious daughter Lumi - you have had to endure an absent mother lately, but you hardly complain, only wonder why mommy has so little holidays these days. I love you to the moon - and far, far beyond - as you know! More than anything, I hope you will be able to follow your dreams and experience wonderful adventures, like I have.

Kirsi Kotilainen

Tampere 20.04.2020

ABSTRACT

Climate change and the ever-growing demand for energy are pushing us to find new ways to manage energy production, distribution, and consumption. This energy transition is enabled, for example, by the digitalization, decentralization, and democratization of the energy system. The energy system is already transitioning from fossil-fuel and large power-plant–based generation toward a flexible system based on renewable energy sources. Traditional transmission grids are being replaced by smart grids enabled by digitalization that facilitate bi-directional flows of information and energy. At the consumption end, smart energy meters, energy monitoring devices and applications, and renewable energy technologies such as solar photovoltaic and battery storages empower energy consumers to evolve into prosumers: the producers and consumers of energy. These prosumers, also referred to as active consumers and energy citizens, are envisioned to play an important role in the sustainable energy system in the future.

While the energy prosumer role has gained more research attention during the past few years, plenty of gaps in completely understanding energy prosumerism still remain. This research focuses on studying the prosumer role in the sustainable energy system. I study the enablers and activities of energy prosumers and explore how the growing number of prosumers may influence the socio-technical energy transition.

The research presents two main perspectives on prosumerism; it explores both the micro and macro-level influences on the energy prosumers. The main research fields of this study are sustainability transitions, innovation studies, and policy. Based on theory and literature review, a novel research framework synthesizing the theoretical concepts and earlier research related to prosumers is introduced.

From the methodology viewpoint, a pragmatic research approach and mixed methods are used to explore the enablers for prosumerism as well as prosumer activities and their impact on the ongoing energy transition.

The research results are displayed in the form of six articles published in international peer-reviewed journals and conferences. The first two articles make propositions about the prosumer role as part of the changing socio-technical energy

and innovation system. The next two articles focus on understanding the micro-level impact on the energy prosumers and examine the producer–consumer, in particular, as a co-developer of energy-related innovations. The remaining two articles address the impact of macro-level policies on prosumers.

Overall, this research contributes to the understanding of the energy prosumer role in the future sustainable energy system. Theoretical contributions are related to the novel research framework that combines the concepts from the socio-technical multi-level perspective, innovation studies, and policy research as well as offers a more pragmatic framework for inquiry in the context of the changing energy system to observe the prosumer role therein. A specific theoretical contribution is made to the technology acceptance model that is tested in the context of external policy influence. Furthermore, the research contributes to innovation studies and especially to the field of user-centric innovations by bringing new results for understanding the factors behind end users' collaboration interests. Practical contributions of the study are related to the understanding of the micro-foundations of prosumer interests toward innovation co-creation activities. Practitioners benefit from evidence concerning the differences between consumers and prosumers, which may help them in designing products and services for these different categories. This improved understanding is necessary, for example, to accelerate the diffusion of renewable energy technologies that is crucial for the sustainability transition. Policy-makers may benefit from the findings related to the policy analysis that combines and compares different prosumer activities with policy mixes and calls for a more holistic and systemic approach for the development of the prosumer related policies.

While prosumer research has increased during the past decade, many future research avenues for the topic exist. For example, more research on prosumer role as part of the sustainability transition can help in designing better policies as well as products and services for consumers and prosumers. Moreover, systemic activities, such as those related to the integration of electric vehicle smart charging into the power system combined with other prosumer activities, offer opportunities for researchers. Furthermore, research concerning novel prosumer-centric business models, for instance related to energy communities, is needed to accelerate the diffusion of sustainable technology solutions.

TIIVISTELMÄ

Ilmastomuutos ja kasvava energian kysyntä ajavat meidät etsimään uusia tapoja hallita energian tuotantoa, jakelua ja kulutusta. Energiajärjestelmä onkin jo siirtymässä fossiilisten polttoaineiden ja suurten voimalaitosten tuotannosta uusiutuviin energialähteisiin perustuvaan joustavaan järjestelmään. Sähköverkot on transformoitu digitalisoinnin mahdollistamana älykkäiksi Smart Grid -verkoiksi, jotka pystyvät siirtämään sekä energiaa että dataa molempiin suuntiin tuotannon ja kulutuksen välillä. Kulutuspäässä älykkäät energiamittarit, seurantalaitteet ja -sovellukset sekä uusiutuvien energialähteiden teknologiat, kuten aurinkosähkö ja akkuvarasto, antavat energiankuluttajille mahdollisuuden kehittyä prosumereiksi eli energian tuottaja-kuluttajiksi (engl. prosumer = producer-consumer). Prosumereilla, joihin viitataan myös nimillä "aktiivinen kuluttaja" ja "energiakansalainen", on tulevaisuudessa tärkeä rooli kestävässä energiajärjestelmässä.

Vaikka prosumerit ovat saaneet lisää huomiota tutkimuksessa viime vuosina, energia prosumerismin ymmärtämisessä on vielä paljon aukkoja. Tämä tutkimus keskittyy selvittämään prosumerien roolia osana kestävää energiajärjestelmää ja sen murrosta. Tutkin prosumereihin liittyviä mahdollistajia, prosumerien toimintaa osana energiajärjestelmää sekä vaikutuksia kestävän kehityksen energiamurrokseen.

Tutkimus on luonteeltaan monialainen, yhdistäen innovaatiotutkimusta, transitiotutkimusta ja myös jossain määrin politiikantutkimusta. Tässä pragmaattisessa tutkimuksessa käytetään sekä kvantitatiivisia että laadullisia tutkimusmetodeja. Tutkimuksen tulokset esitetään liitteenä olevien kuuden vertaisarvioidun konferenssi ja -journaaliartikkelin avulla. Ensimmäiset kaksi artikkelia esittävät propositioita prosumerin roolista osana muuttuvaa sosio-teknistä energia- ja innovaatiopelikenttää. Seuraavat kaksi artikkelia keskittyvät ymmärtämään mikrotason vaikutusta näihin toimijoihin ja tutkivat erityisesti energiaan liittyvien innovaatioiden yhteiskehittämistä. Lopuksi kaksi artikkelia käsittelevät makrotason politiikkatoimien vaikutusta prosumereihin.

Tutkimuksen pääkontribuutio on ymmärryksen lisääminen kuluttajan muuttuvasta roolista osana energiajärjestelmää. Teoriakontribuutiot kytkeytyvät uusiin tapoihin yhdistää keskeisiä teorioita kestävän kehityksen transitiotutkimuksesta, innovaatiotutkimuksesta sekä politiikan tutkimuksesta.

Käytännön elämään vaikuttavat kontribuutiot liittyvät empiirisiin tutkimustuloksiin esimerkiksi tavallisten kuluttajien ja prosumereiden eroista. Tietämyksen lisääminen auttaa teknologia- ja palveluyrityksiä suunnittelemaan tuotteita ja palveluita, jotka sopivat erilaisiin tarpeisiin, joka voi edelleen auttaa nopeuttamaan uusiutuvaan energiaan liittyvien innovaatioiden leviämistä ja siten edistää kestävää kehitystä.

Prosumer -tutkimuksessa on edelleen paljon tilaa uudelle tieteenharjoitukselle. Esimerkiksi energiayhteisöt ovat yleistymässä ja tutkimus niiden roolista osana energiajärjestelmää on vasta käynnistynyt. Tutkimalla energiayhteisöjä pystytään lisäämään ymmärrystä niiden vaikutuksesta esimerkiksi sähköverkkoon ja lainsäädäntöön. Toisaalta myös yksittäisten aktiviteettien ja ajureiden tutkimuksessa on vielä paljon mahdollisuuksia. Esimerkiksi systeemiset ja integroidut ratkaisut, kuten sähköautojen käyttäminen osana kysyntäjoustoa, tarjoavat hyviä tutkimusaiheita. Lisäksi erityisesti uudet liiketoimintamallit liittyen prosumereihin ja energiayhteisöihin kaipaavat selkeyttämistä ja kokeiluja sekä regulaation muunnoksia.

CONTENTS

ABBREVIATIONS

Abbreviation	**Description**
AMI	Advanced metering infrastructure
AMR	Automatic meter reading
ANOVA	Analysis of variance
API	Application programming interface
ATU	Attitude towards using
AVE	Average variance extracted
BC	Blockchain
BEV	Battery electric vehicle
CAPEX	Capital expenditure
CHP	Combined heat and power
CO_2	Carbon dioxide
CPP	Critical peak pricing
CR	Composite reliability
DBE	Digital business ecosystem
DER	Distributed energy resources
DG	Distributed generation
DIY	Do-it-yourself
DMS	Demand side management
DOI	Diffusion of innovations
DR	Demand response
DSO	Distribution system operator
EC	European commission
EL-TRAN	Transition to a resource-efficient and climate-neutral electricity system
EP	Economic policy
EPI	Environmental policy instrument
EPRG	Energy policy research group
EU	European union
EV	Electric vehicle

f^2	f-squared (effect size)
FIT	Feed-in-tariff
GW	Gigawatt
HEMS	Home energy management system
HTMT	Heterotrait-monotrait
ICE	Internal combustion engine
ICT	Information and communication technology
IDT	Innovation diffusion theory
IoE	Internet of Energy
IoT	Internet of Things
IPMA	Importance-performance matrix
ISV	Independent software vendor
IT	Information technology
KMO	Kaiser-Meyer-Olkin
kW	Kilowatt
LEMENE	Lempäälän energiayhteisö
Li-ion	Lithium-ion
MAE	Mean absolute error
MAR	Missing at random
MLP	Multilevel perspective
MOAB	Motivation-opportunity-ability-behavior
NEP	Non-economic policy
NIMBY	Not in my back yard
NPD	New product development
OPEX	Operational expenditure
OSS	Open source software
P2P	Peer-to-peer
PCA	Principal component analysis
pDEEF	Prosumer centric digital energy ecosystem framework
PEOU	Perceived ease of use
PESTEL	Political-economic-social-technological-environmental-legal
PHEV	Plug-in hybrid electric vehicle
PLS	Partial least squares
PLS-SEM	Partial least squares structural equation model
ProCem	Prosumer centric energy ecosystem

PU	Perceived usefulness
PUE	Perceived usefulness economic
PUF	Perceived usefulness functional
PV	Photo voltaic
Q^2	Q-squared
R&D	Research and development
R^2	R-squared
RES	Renewable energy sources
RET	Renewable energy technologies
RMSE	Root mean square error
RQ	Research question
RTU	Real time use
SEI	Sustainable end user innovation
SEM	Structural equation model
SEP	Sustainable EV-Prosumer (framework)
SNM	Strategic niche management
SPSS	Statistical Package for the Social Sciences
STRN	Sustainability transition research network
TAM	Technology acceptance model
TM	Transition management
TOU	Time of use
TPB	Theory of planned behavior
TPB	Theory of planned behavior
TRA	Theory of reasoned action
TSO	Transmission system operator
UNIL	University of Lausanne
V2G	Vehicle to grid
V2H	Vehicle-to-home
VAS	Value added service
VBN	Value-belief-norm
VIF	Variance inflation factor
VPP	Virtual powerplant

ORIGINAL PUBLICATIONS

Publication I Kotilainen, K., Mäkinen, S. J., Järventausta, P., Rautiainen, A., & Markkula, J. (2016). The role of residential prosumers initiating the energy innovation ecosystem to future flexible energy system. In 13th International Conference on the European Energy Market (EEM), Porto, Portugal, June 2016, (pp. 1-5). IEEE.

Publication II Kotilainen, K., Sommarberg, M., Järventausta, P., & Aalto, P. (2016). Prosumer centric digital energy ecosystem framework. In Proceedings of the 8th International Conference on Management of Digital EcoSystems (MEDES), Hendaye, France, November 2016, (pp. 47-51). ACM.

Publication III Kotilainen, K., Valta, J., & Järventausta, P. (2017). How consumers prefer to in-novate in renewable energy and what they expect to get in return for co-creation. In 2017 International Conference on Engineering, Technology and In-novation (ICE/ITMC), Madeira, Spain, June 2017, (pp. 872-878). IEEE.

Publication IV Kotilainen, K., Saari, U. A., Mäkinen, S. J., & Ringle, C. M. (2019). Exploring the microfoundations of end-user interests toward co-creating renewable energy technology innovations. Journal of Cleaner Production, 229, (pp. 203-212).

Publication V Kotilainen, K., & Saari, U. (2018). Policy Influence on Consumers' Evolution into Prosumers—Empirical Findings from an Exploratory Survey in Europe. Sustainability, 10(1), 186.

Publication VI Kotilainen, K., Mäkinen, S. J., & Valta, J. (2017). Sustainable electric vehicle-prosumer framework and policy mix. In IEEE Innovative Smart Grid Technologies-Asia (ISGT-Asia), Auckland, New Zealand, December 2017, (pp. 1-6). IEEE.

Author's contributions to the publications

	Kirsi Kotilainen			Description of authors' contributions
	C1[1]	C2	C3	1) C1 = Conception, design or analysis, and interpretation of data; C2 = Drafting or critically revising the paper; C3 = Final approval of the version to be published.
Article I	x	x	x	Kirsi Kotilainen developed the propositions and wrote this article. Other authors commented and reviewed the propositions and critically reviewed and edited the manuscript. Article was peer reviewed and minor corrections were made by Kirsi Kotilainen based on the review results. Article was presented at the conference and is available in IEEE Xplore digital library.
Article II	x	x	x	Kirsi Kotilainen designed the article, developed the propositional framework, and wrote the article. Pami Aalto and Pertti Järventausta critically reviewed and edited the article. Article was peer reviewed and as a result of the review, the article was reduced from original eight pages to four pages by Kirsi Kotilainen. Article was presented at the conference and is available in ACM digital library.
Article III	x	x	x	The consumer survey was designed in a research group of which Kirsi Kotilainen was a member. Other researchers collected the survey data. Kirsi Kotilainen conceptualized and designed the paper and wrote the draft. Kirsi Kotilainen and co-authors analyzed and interpreted the data, drafted and reviewed the paper, and revised it. Article was peer reviewed and minor corrections were made by Kirsi Kotilainen based on the review results. Article was presented at the conference and is available in IEEE Xplore digital library.
Article IV	x	x	x	The consumer survey was designed in a research group and other researchers collected the data. Kirsi Kotilainen conceptualized and designed the paper. Kirsi Kotilainen, Ulla A. Saari, and Christian M. Ringle designed the data analysis and analyzed and interpreted the data. Kirsi Kotilainen drafted the Introduction, Theory, Hypothesis, and Conclusions, and Ulla A. Saari drafted the Data Analysis and Results and reviewed the paper. Saku Mäkinen drafted and wrote the Abstract. Christian M. Ringle advised on the analysis and revised the paper. Article was peer reviewed and as a result the first version of the article was rejected with an invitation to resubmit if improved. Kirsi Kotilainen re-wrote the Introduction and Theory sections and made other corrections. Ulla A. Saari and Christian M. Ringle revised the analysis section and improved the presentation of the results. Article was accepted after the re-submit and has been published in the Journal of Cleaner Production.
Article V	x	x	x	The consumer survey was designed in a research group of which Kirsi Kotilainen was a member; the data was collected by other researchers. Kirsi Kotilainen was the main author and conceptualized and designed the paper and developed the conceptual model. Kirsi Kotilainen wrote the Introduction and Theory as well as the Discussion and Conclusions. Ulla Saari analyzed and interpreted the data using PLS-SEM; Kirsi Kotilainen supported the analysis. Ulla Saari wrote the Results. The paper was reviewed by both authors. The article was peer reviewed and minor corrections were requested. Kirsi Kotilainen and Ulla A. Saari revised the article based on the reviewer feedback. Article was accepted and published in the Sustainability journal after the corrections.

Article VI	x	x	x	Kirsi Kotilainen conceptualized and designed the paper and did the literature review. Kirsi Kotilainen and Jussi Valta collected the policy data. Kirsi Kotilainen analyzed and interpreted the data. Kirsi Kotilainen drafted and critically revised the paper. Jussi Valta drafted some sections of the paper. All co-authors reviewed and revised the paper. Article was peer reviewed and reviewer comments were considered in the final version of the paper. Article was presented at the conference and is available in IEEE Xplore digital library

1 INTRODUCTION

Energy prosumers are emerging as new actors in the energy system with the introduction of affordable renewable energy technologies (RETs) such as solar photovoltaic (PV) panels and smart energy meters. These novel technology solutions enable consumers to produce, store, and sell energy. Energy prosumer research has gained more attention over the past decade, especially since the introduction of smart grids and smart metering infrastructure. The research focus on prosumers has been dominated by science and engineering studies (e.g., Malamaki et al., 2017; Rathnayaka et al., 2012) and innovation research (Heiskanen and Lovio 2010), but prosumers are also recognized in social sciences (Miller and Senadeera 2017; Wüstenhagen et al. 2003) and increasingly in sustainability transition studies (e.g., Schot et al., 2016).

Active consumers and prosumers are envisioned to contribute to the sustainable development of the energy system, but the actual prosumer base growth depends on multiple factors and achieving wide-spread prosumerism still faces many barriers today. Despite the growing interest toward prosumerism, the prosumer base is not growing as fast as desired in many markets and a holistic approach to enable the prosumers is missing. For example, Finland's Energy and Climate Strategy (Huttunen 2017) and its implementation plan (Ympäristöministeriö 2017) highlight the importance of active consumers' contribution in achieving the 2030 emission reduction targets; however, concrete actions and incentives to engage the consumers are not clearly defined. This dissertation focuses on casting light on the prosumer role as part of the ongoing energy system's sustainability transition. Sustainability is typically divided into environmental, social and economic sustainability, sometimes called the triple bottom line of sustainability (e.g. Giddings et al. 2002). Sustainable energy system has been described e.g. as a transition "of both the energy supply and the energy demand side (economy) while the per capita energy service levels (equity) are sufficiently maintained for the duration and the environmental constraints are met (environment)" (Sgouridis and Csala 2014, p 2609). I set to explore both the macro and micro level influences of the consumer-to-prosumer evolution. I furthermore reflect on some of the key effects of prosumerism on the energy transition.

1.1 Motivation, background, and research gaps

Energy systems are currently going through a transition from large centralized power plants and fossil fuel–based energy sources toward more decentralized systems based on renewable energy. Traditional electricity grids are being transformed into digitally enabled smart grids that can bi-directionally move energy and data. At the same time, renewable energy generation is becoming increasingly mainstream. Owing to the burning need to mitigate the effects of climate change, the energy system transition is unavoidably a "low carbon transition" (Cherp et al. 2018). However, it will take some time before we can call our energy systems truly sustainable. While technology solutions for producing, storing, and distributing renewable energy are already available, challenges remain concerning the technology implementation, policy support, consumer acceptance, and economic feasibility. The lock-in into fossil fuels as energy sources still persists globally (G. C. Unruh and Carrillo-Hermosilla 2006). For example, the energy sector still generated 75% of Finland's total emissions in 2017 (Statistics Finland 2019)[1]. Although the transition clearly progresses, there is a need to further accelerate the pace of emission reduction to maintain tolerable climate conditions (IPCC, 2018).

Prosumers are emerging actors in the sustainability transition of the energy system. Sustainability transition research is an interdisciplinary field that broadly draws from various fields of sciences, such as innovation and policy studies (Köhler et al. 2019; Rogge and Reichardt 2016). Energy transition can be seen as part of the sustainability transition, although it can also be claimed that the transition is not necessarily sustainable in all aspects (Cherp et al. 2018). Sustainability transition research has significantly grown over the past two decades (Köhler et al. 2019). The global challenge of climate change is complex and fits well into the definition of a "wicked problem" (Head and Alford 2015). Hence, research must address the systemic complexity, social aspects, technology evolution, global politics, and many other issues affecting the goal of achieving an emission-free society. Marknad et al. (2012, p. 956) define sustainability transition as "long-term, multi-dimensional, and fundamental transformation process through which established socio-technical systems shift to more sustainable modes of production and consumption." The

[1] Including both emission trading and non-emission trading sectors

energy system transition is such a transition that facilitates the move toward a decarbonized, digitalized, decentralized, and democratized system.

Prosumers are actors in the energy sector that has traditionally been dominated by large incumbent companies. When I started this research in early 2016, prosumers were not well-understood at all—the entire prosumer research area was full of gaps to be filled. First of all, most of the research was done in silos. In technology and science research, prosumers were mainly considered from the electricity grid perspective as energy producers of distributed and variable energy that challenge the energy system both technically and commercially. To date, one of the main research topics is the effects of renewable energy sources (RES) and distributed generation (DG) on the power system (Gensollen et al. 2016; Malamaki et al. 2017; Ramachandran et al. 2012). The shift toward variable energy sources poses novel challenges; hence, increasing the energy system's flexibility is critical. Residential energy production effects on the system have also been receiving research attention (Bellekom et al. 2016; Gautier et al. 2018; Rosen and Madlener 2016). Another key research topic concerning energy prosumers is flexibility and residential demand side management (Liu et al. 2017; Pinto et al. 2017; Saele and Grande 2011). In contrast, social sciences research has focused on the consumer and prosumer acceptance of RETs. For example, windfarms have been widely studied from this perspective (Wustenhagen et al. 2007). Furthermore, behavioral reasons behind the willingness to accept and adopt RETs and new ways of consuming energy have been receiving increased interest in the social sciences research (Frederiks et al. 2015; Hertig and Teufel 2016). In addition, innovation studies have investigated end-users as adopters of RETs or co-creators of innovations to some extent; however, several research gaps still remain (Heiskanen et al. 2018; Hyysalo et al. 2013; Juntunen 2014; Köhler et al. 2019; Olkkonen et al. 2017).

Besides the growing amount of research on various aspects of prosumerism, considerable research opportunities exist both in the individual research streams and on the holistic understanding of the prosumer role in the sustainability transition. Sustainability Transition Research Network (STRN), that today involves almost 2000 researchers, has recently proposed an agenda comprising eight research streams: general understanding of sustainability transitions, politics, governance, civil society, business & industries, practice & everyday life, geographical scope, and ethical considerations (Köhler et al. 2019). Prosumer-centric research gaps can be addressed in several of these streams. Some of the gaps are still relevant for the research at hand.

First, transition research has focused on the systemic and multi-actor level in transitions (Köhler et al. 2019; Markard et al. 2012; Schot et al. 2016). While the systemic nature of the transition is extremely important to understand, the single actor level has received less focus (Köhler et al. 2019; Markard et al. 2012; Wittmayer et al. 2017). Prosumers are such single actors in the sustainability transition. While some industry reports have covered residential prosumers from various perspectives (European Commission 2017; IEA-RETD 2014; Kampman et al. 2016), according to my understanding, prosumer role has not been studied in a holistic way from the socio-technical perspective.

Second, governing the transitions includes research on policy mixes and underlying processes (Köhler et al. 2019; Rogge and Rechardt 2013; Rogge and Reichardt 2016). Policies play a key role in accelerating the diffusion of sustainable technologies, such as solar PV (Negro et al. 2012; Rogge and Johnstone 2017a; Rogge and Reichardt 2016). Policy mixes concerning prosumers have been narrowly studied, focusing on solar PV or smart metering policies (European Commission 2017), but a holistic view of policy mixes covering different prosumer activities, such as energy production, energy sales, energy storage, flexibility and innovation co-creation, is missing (Kotilainen, 2017).

Third, the role of grassroots innovations in shaping the broader societal transformation is recognized as a continuous area of research interest (Hossain 2016; Köhler et al. 2019; Van Der Schoor and Scholtens 2015). Consumers' potential to innovate and co-create has received research attention (Heiskanen and Lovio 2010; Hossain 2016; Hyysalo et al. 2013; Kotilainen, Jarventausta, et al. 2016; Nygren et al. 2015; Ornetzeder and Rohracher 2006), but the prosumer perspective is often missing in these studies; further research about prosumers as innovators is still called for.

Fourth, understanding sustainability transition in practice and everyday life calls for understanding the prosumer contributions and role as part of the wider system in this respect as well as studies on users as active participants in socio-technical change: for example, from the perspective of self-organizing, accelerating markets, and producing social innovations (Naus et al. 2015).

Finally, in addition to the typical qualitative methods, sustainability transition research calls for more quantitative research as well as better connection of macro- and micro-level analysis (Köhler et al. 2019). This dissertation focuses on addressing some of these research gaps from the energy prosumer perspective.

1.2 Research objectives and research questions

To address the above discussed research needs, this dissertation aims to understand the energy prosumer role in the sustainable energy system. The first objective of this study is to contribute to the holistic understanding of the prosumer as an actor in the socio-technical energy transition. To achieve this, I investigate the enablers of consumer-to-prosumer evolution and connect them with prosumer activities as well as explore how the activities may influence the energy transition. The second objective is to observe the prosumer from the two perspectives that together form a combined micro- and macro-level inquiry. Thereby, I study prosumers as innovators, especially focusing on the micro-foundations to gain a better understanding of the bottom-up nature of prosumer drivers. While micro-foundations (e.g. Barney and Felin 2013) have multiple interpretations, they in this context refer to the drivers of individuals' interests for co-creation and collaboration. Next, I observe the macro-level policy influence and policy mixes to explore how policy influences the consumer-to-prosumer evolution as well as the prosumer activities.

This dissertation fosters an integrative approach and relies on a combination of inputs from innovation studies, policy sciences, and sustainability transition research to provide a broad view on the energy prosumers' role in forming a sustainable energy system (Figure 1).

The research questions (RQs) for this study are defined as follows:

RQ1: A) How do different enablers contribute to consumers' evolution into prosumers? B) What is the role of policy as an enabler?

RQ2: A) What are the core prosumer activities in the energy system? B) How do prosumers contribute to the adoption and co-creation of energy innovations in energy system transition?

RQ3: What is the prosumers' role in energy transition and how do prosumers influence the transition?

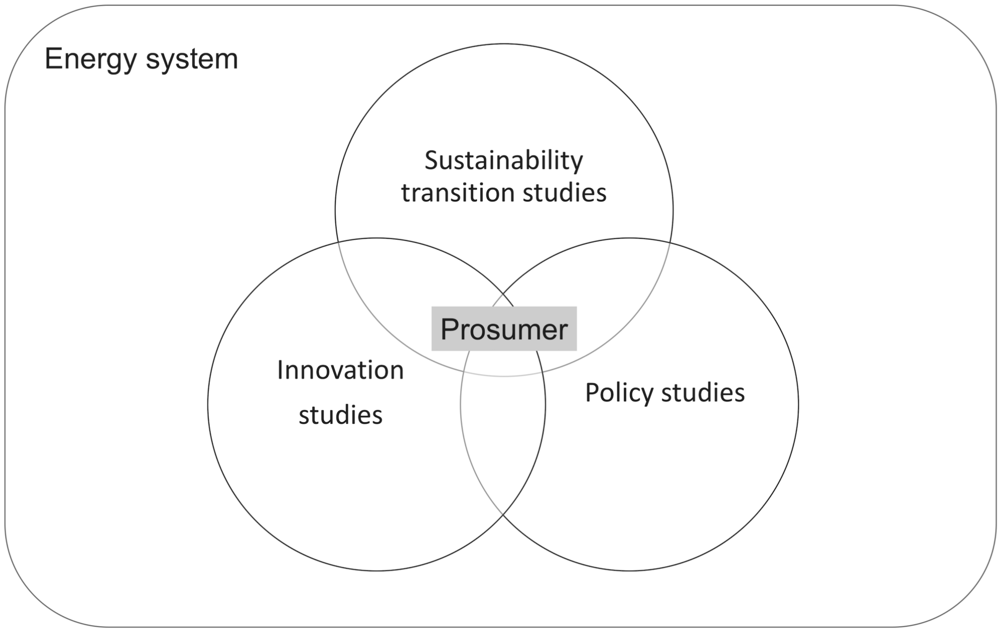

Figure 1. Main research fields and the empirical context of the study.

RQ1 inquiries about the prosumer *enablers*, which in this context refer to the technological, political, economic, or individual factors or resources that support the consumer-to-prosumer evolution. Enablers are necessary for prosumers to exist (IEA-RETD 2014). For example, most of the technology solutions, such as solar PVs, are prerequisites for prosumer activities. The term *driver* is sometimes used instead of enabler to emphasize the factors or resources that more decisively affect the consumer-to-prosumer evolution. Banning of internal combustion engine (ICE)-based vehicles, such as diesel cars, could be an example of a macro-level policy driver for prosumerism. Similarly, the economic incentives that offer very attractive value proposition for energy production or sales are another examples of drivers for prosumerism. This dissertation first broadly reviews different prosumer enablers and then focuses (in appended articles) on understanding *policy as an enabler*, which forms one of the two distinctive *perspectives* for this study. Articles V and VI address the perspective of policy as an enabler. The other enablers are discussed in more general level.

RQ2 focuses on the prosumer *activities*, which refer to the ways the energy prosumers engage themselves in different actions in the context of the energy system. Prosumer activities have been described by, for example, the European Commission (EC) (European commission 2016) and can be summarized as energy production, energy storage, energy sales, and participation in flexibility. In addition, innovation is considered as one of the core activities of energy prosumers, and it is studied as the other perspective of this dissertation in the appended Articles III and IV.

RQ3 attempts to understand the prosumers' role in the transition and their influence the sustainability *transition* of the energy system toward a more decentralized and digitalized RES-based system. In this research, I "zoom" into the energy prosumer as an actor in the energy system transition. Sustainability transition is a complex phenomenon encompassing multiple research streams, each with a research agenda (Köhler et al. 2019; Markard 2017). Hence, covering all possible potential influences of energy prosumerism in this sense is impossible. The present study focuses on positioning prosumers in the socio-technical multi-level perspective (MLP) (Geels and Schot 2007) and identifying some of their key influences on sustainability, the energy system and market, and energy innovations. One way to approach a single actor in transition is through understanding its role (Wittmayer et al., 2017). A "role" can be defined in multiple ways, one of which is based on the actors' activities and attitudes (Turner, 1990; Wittmayer et al., 2017). The prosumer as an actor in the energy transition is analyzed through enablers, activities, and their impact on energy transition. Using the enablers and activities to describe the prosumer role are loosely based on a simplified version of the intra-actor centric view of the ecosystem value creation (Talmar et al., 2018).

This research is not tightly limited to a certain country; however, the research focus has been on Europe, with somewhat more emphasis on Finland. Furthermore, the research interest is mainly on small-scale residential solar prosumers and electric vehicle (EV) owners rather than on commercial or industrial-scale prosumers.

Articles I and II explore the prosumers in the energy transition. The two perspectives of this dissertation, "prosumers as innovators" and "policy as an enabler," are discussed in the appended Articles III–VI. Table 1 summarize the RQs, analytical focus, and appended articles.

Table 1. Summary of the research questions, analytical focus, and appended articles.

Research question		Analytical focus	Objectives	Publication (main focus)
RQ1.	A) How do different enablers contribute to consumers' evolution into prosumers? B) What is the role of policy in this regard?	Enablers	Identify the key enablers influencing consumer-to-prosumer evolution Macro level perspective: policy as an enabler	V, VI
RQ2.	A) What are the core prosumer activities in the energy system? B) How do prosumers contribute to the adoption and co-creation of energy innovations?	Activities	Identify the key activities and map them with enablers Micro level perspective: prosumers as innovators	III, IV
RQ3.	What is the prosumers' role in energy transition and how do prosumers influence the transition?	Transition	Contribute to the understanding of the prosumer role in the energy transition in terms of sustainability, energy system, and market and energy innovations	I, II

1.3 Structure of the dissertation

The dissertation is structured as follows. A literature review is presented in chapter 2, in which prosumer-related research is reviewed, the theoretical contexts for the research are described, and the two special perspectives of the dissertation are introduced. Chapter 2 is concluded by introducing the analytical research framework that forms the frames for the inquiry by bringing together the findings from literature and theory. Chapter 3 then explains the research methodology and describes the data sources and analysis used in the research. Chapter 4 summarizes the findings based on the appended articles, and chapter 5 discusses the findings in light of the RQs. Chapter 6 concludes the paper by addressing the key contributions of the research on theory and practice and discusses the limitations, reliability and validity considerations, as well as potential future research opportunities. Figure 2 illustrates the dissertation structure.

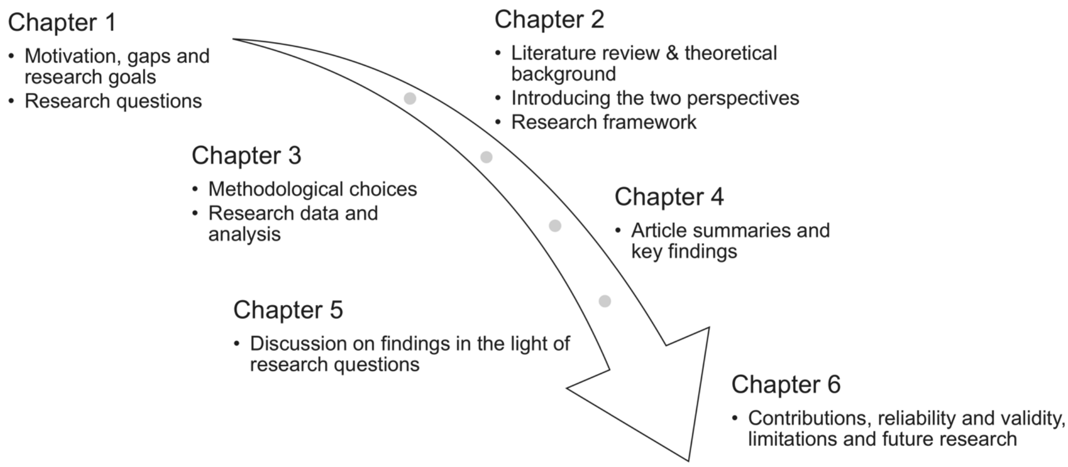

Figure 2. The dissertation summary structure

2 THEORETICAL AND EMPRICAL FOUNDATION OF THE RESEARCH

This chapter dives into more detail on the energy prosumers and their role in the energy transition by reviewing extant literature. First, the literature review focuses on the energy prosumer; different ways to define the prosumers are reviewed and the prosumer enablers and activities are discussed. Second, the attention moves to the two *perspectives* of this study, which are connected to the enablers and activities: first the perspective of *prosumers as innovators* is introduced, followed by *policy as an enabler*. Third, the key theories related to sustainability transition research are introduced, and the prosumers are reflected as part of the energy transition. Finally, the analytical research framework based on the key theoretical and empirical concepts is presented.

2.1 Meet the energy prosumer

Alvin Toffler first coined the term prosumer in his book *The Third Wave* (Toffler 1981). Prosumer is not a new concept as such. Prosumers already existed in the pre-industrial world (the "first wave"); most people produced and consumed their food, goods and services. However, introduction of mass-production during the "second wave" industrialization almost entirely separated consumption and production. According to Toffler, the society is moving toward a "third way" in which there are again more reasons for modern people wanting to produce and consume their own products and services; People have more time besides work, services are more expensive and do-it-yourself can be seen as self-actualization which brings satisfaction. (Toffler 1981)

Philip Kotler (Kotler 1986a, 1986b) soon after developed the idea of prosumerism further. Kotler (1986a) identified two types of prosumers; *the avid hobbyist* and *the archprosumer*. The first mainly produces to exchange but has some hobbies where goods or services are produced to use. The latter refers to people who prefer to make almost everything by themselves thus avoiding the mass consumption society. In the early days, prosumers were typically considered as contributors to media content or, in some cases, professional customers requiring close-to-professional quality products: for example, digital cameras. Prahalad and Ramaswamy (2004) later studied prosumers in the context of value co-creation. Tapscott and Williams (2008) furthermore observed prosumers in the context of online economy, networking and collaboration (the "wikinomics"). In their work, Ritzer and Jurgenson (2010) also discussed how digitalization—e.g., in the form of Facebook, Wikipedia, YouTube, and blogging—has enabled a more widely spread emergence of prosumers who have actual power and influence on business and society.

The word "prosumer" is derived from "*pro*ducer" and "con*sumer*" as per Toffler's original description. However, other descriptions for the term can be also found. For example, prosumer can be seen as a "*pro*fessional con*sumer*" (Kotler 1986a) that requires nearly professional quality equipment, such as digital camera or solar PV, or that participates in the co-design of novel innovations to co-create value (Prahalad and Ramaswamy 2004). Furthermore, in particular energy prosumers can be seen as "*pro*vider con*sumers*" (Kotilainen 2019) that may not actually produce energy but provide access to their energy-related resources, such as hot water tanks or the heating system, for flexibility and demand response (DR) purposes. In the extant literature the term prosumer has been extended to mean more than just individuals, which were the main focus of the earlier literature. Especially in the energy area prosumers are usually categorized as industrial, commercial and residential entities. Prosumers in the energy field started to appear roughly a decade ago, after the introduction of solar PV technology and smart grids. Currently, majority of the prosumer research, in terms of publications, is related to energy prosumer in particular.

The importance of prosumers has been acknowledged by the EC (European commission 2016), which currently defines energy prosumers as *active consumers* and further describes them as "a customer or a group of jointly acting customers who consume, store, or sell electricity generated on their premises, including through aggregators, or participate in DR or energy efficiency schemes, provided that these activities do not constitute their primary commercial or professional activity".

Energy prosumers are sometimes also referred to as *energy citizens*, emphasizing their role as active agents in the sustainability transition (Kampman et al. 2016). Energy community initiatives, for example, are seen as a way to increase the use of

RES and therefore can help push the energy system toward a more sustainable future, despite what choices are made concerning the national energy mix. Furthermore, Schot et al. (2016) studied end-user role in the socio-technical sustainability transition and recognized five different types of potentially influential users, some of which could be prosumers and others active consumers: *user-producer*, *user-legitimator*, *user-intermediary*, *user-consumer*, and *user-citizen*. Out of these, the user-producer is closest to the notion of producer-consumer, for example a household producing part of their energy using solar PV.

Energy prosumers come in different sizes and types, including residential households, commercial establishments, and large industrial sites. As prosumers are typically considered customers from the energy utility's point of view, energy production and consumption volumes determine the category to which a prosumer belongs from the energy system and market perspective. Residential prosumers usually have installation below 10 kW, but definitions vary by country (European Commission 2017; IEA-RETD 2014). Most countries have limitations concerning the participation in the energy markets that typically limit especially the opportunities of small-scale prosumers. New regulations, business models, and market practices are however implemented to provide more opportunities for small prosumers to more actively participate in the energy markets.

While the typical residential energy prosumer uses solar PV to generate electricity, prosumers may use different energy sources and produce different types of energy. Wind turbines, biomass processors, and solar thermal collectors are also available for residential prosumers. Commercial or industrial-scale prosumers may use sources other than RES, such as gas, as part of their production system. In addition to electricity, heating and cooling are potential outputs of self-production.

Another aspect worth considering is the prosumers' dependence on the power grid. Most prosumers self-produce only part of their total energy demand or are seasonally dependent on the grid (European Commission 2017). Self-consumption rates are used to describe the percentage of energy used at the production location (Dehler et al. 2017). These rates are usually higher for commercial prosumers who require energy during day-time than for residential households that typically consume more energy during mornings and evenings when solar power is not available. Off-grid prosumers exist as well, particularly in areas where the grid is not available; for example, in many developing countries, self-produced energy may be the only option for generating electricity, heating, or cooling. In developed markets, for example, in Germany (Flaute et al. 2017), so-called off-grid phenomena have been feared to cause an increasing number of residents and businesses to disconnect from the grid, causing commercial challenges for the utilities to maintain the quality of service and price levels (IEA-RETD 2014). Energy communities and self-sustaining energy districts are currently emerging in many European markets, raising again the discussion on the need to update the regulation of energy production, storage, and sale in these evolving circumstances (see e.g., https://www.rescoop.eu/_blog). Table 2 summarizes some of the different ways literature has approached the prosumers.

Table 2. Different interpretations of (energy) prosumers based on literature.

Definition	Description	Literature examples
Producer–consumer	Produces and consumes goods and services	Toffler, 1981; Ritzer and Jurgenson 2009
Provider–consumer	Provides resources for flexibility purposes	Kotilainen, 2019
Professional consumer	Co-designs innovative solutions Acquires professional equipment	Kotler, 1986; Prahalad and Ramaswamy, 2004
User-producer, user-consumer, user-legitimator, user-intermediary	Users who produce, innovate, test, advocate, or collaborate in different levels of the socio-technical transition	(Schot et al. 2016)
Energy citizen, user-citizen	Active citizens that advocate change in the energy system	(Kampman et al. 2016; Schot et al. 2016)
Active consumer	Energy market participants and consumers that produce, store, sell, and participate in flexibility	(European commission 2016)

So, there are multiple interpretations for energy prosumers and it is hence important to further elaborate in the context what kind of prosumers one is observing. This dissertation mainly follows the EC definition of active consumers and hence considers energy prosumers to be producers, storers and sellers of energy as well as providers of flexibility resources. In addition, consumers who adopt novel energy solutions and co-create in the context of energy innovations are in the scope of this research. Furthermore, the focus is on small-scale residential prosumers, rather than commercial or industrial ones.

It should perhaps be noted that when I first started research on prosumers, I considered them mainly as residential solar energy producers. Later my own thinking changed and I wanted to explore prosumers more holistically as I began to see a lot of synergies between different types of prosumption. Hence the broad approach is applied to the prosumers and their role in the energy system. Figure 3 summarizes these slightly different interpretations of energy prosumers in the context of this dissertation.

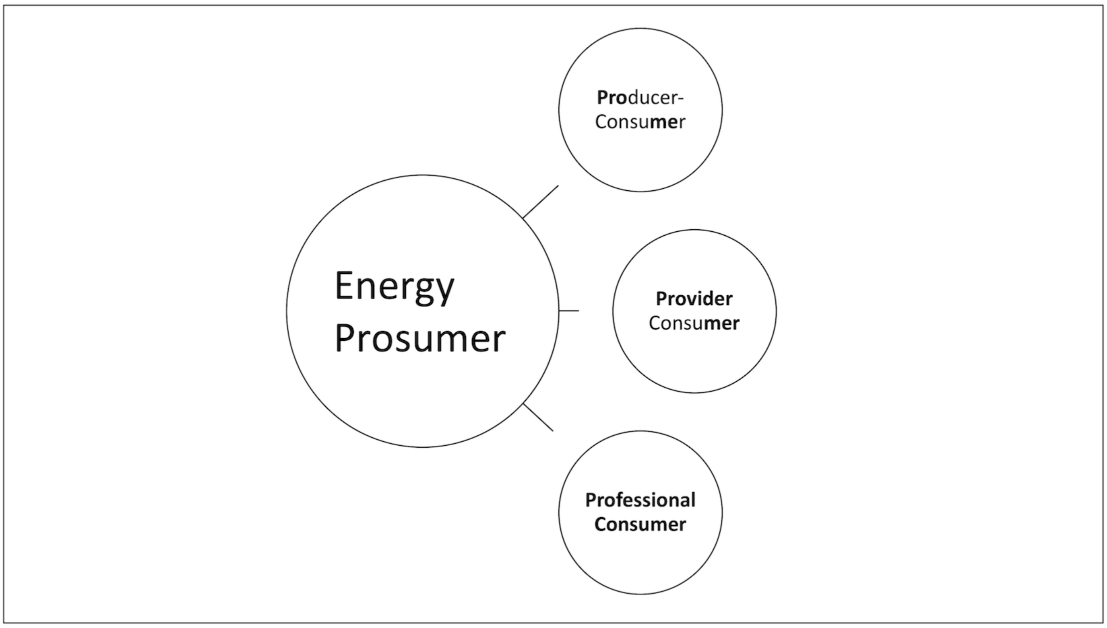

Figure 3. Different interpretations of the term " energy prosumer," adapted from (Kotilainen 2019).

In terms of the producer-consumers, the solar energy prosumer base in several European markets, such as Germany and the UK, has rapidly grown during the past decade owing to more affordable solar PVs and the introduction of policy schemes such feed-in tariffs (FITs). On the contrary, solar prosumer base still remains small in other markets that do not offer attractive incentive schemes to boost the adoption of solar PVs, EVs, and other RETs. For example, Germany's prosumer base rapidly grew after the introduction of FITs, which allows for attractive economic incentives for feeding energy into the power grid; Germany already has millions of prosumers (Brunisholz 2019; European Commission 2017; Flaute et al. 2017; Ossenbrink 2017). Finland, however, does not incentivize solar energy production and has roughly 10,000–15,000 prosumers (Ahola 2019; Bhatti et al. 2018)

2.2 Prosumer activities and enablers

Higher consumer and prosumer engagement is called for in current energy and environmental strategies (Ympäristöministeriö 2017). Prosumers can get involved in the energy system in various ways. EC (European commission 2016) roughly defined prosumer activities as energy consumption, production, sales, storage, and flexibility. In this dissertation, innovation co-creation is added to the list because it is commonly linked to prosumers (Hyysalo et al. 2013; Nidumolu et al. 2009; Prahalad and Ramaswamy 2004).

For consumers to evolve into prosumers, the correct combination of enablers is important (IEA-RETD 2014). Many technology enablers are already at a good level of maturity, but the prosumer base has not even reached close to its potential in most markets (Kampman et al. 2016; Sajn 2016). Some of the features of adopting sustainable innovations could be summarized as follows:

- To affect sustainability, a large number of consumers need to adopt them (Schwartz, 1977).
- Policy incentives are needed to accelerate the adoption of sustainable innovations (Rogge and Reichardt 2016).
- In addition to financial factors, environmental awareness and attitude may play a role in the consumer adoption of sustainable technologies (Scarpa and Willis 2010).

IEA-RETD identified several drivers for prosumerism: technology economic, behavioral, and national conditions (IEA-RETD 2014). Next, the core enablers related to technology, economic factors, policy, and individual factors are reviewed and discussed in the context of prosumer activities. Figure 4 summarizes these.

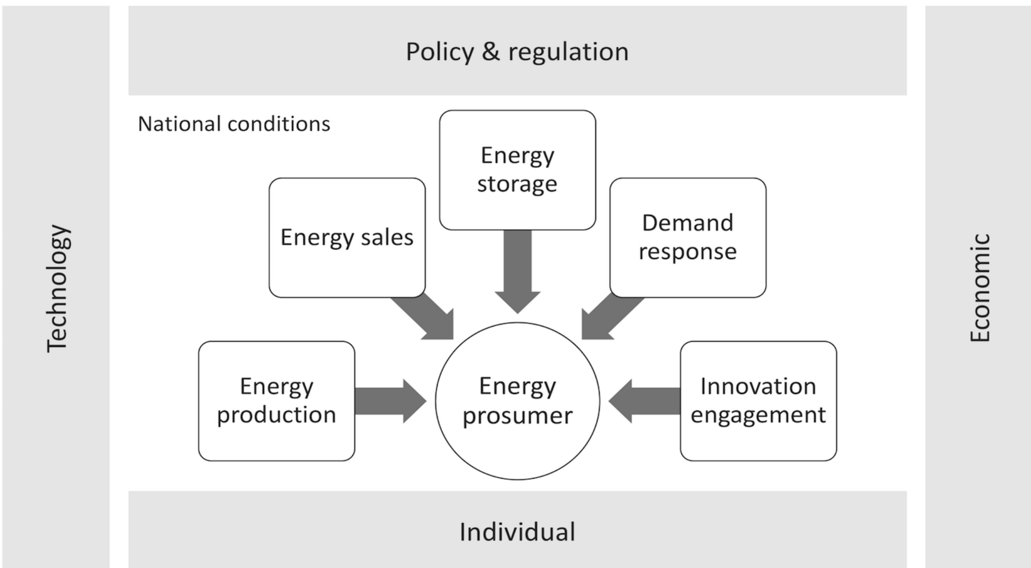

Figure 4. Prosumer enablers and activities, adapted from (Kotilainen 2019).

The prosumer activities depicted in the middle of Figure 4 are discussed next. First, the energy production, energy sales, energy storage and demand response activities and their key enablers are discussed. Second, the two perspectives of this dissertation: *policy as an enabler* and *prosumers as innovators* are discussed in separate chapters in more detail.

2.2.1 Energy production

A typical residential energy prosumer is a household that generates electricity using rooftop solar PV panels. energy sources and outputs are also possible, including wind, solar thermal, and biomass conversion into heat and cooling. Energy production is dependent on the availability of suitable RETs. Solar PVs have technologically and commercially matured during the past decades, making them more efficient and affordable for small-scale producers. Solar PV diffusion has been widely studied (Karakaya et al. 2015; Masson et al. 2014; J. Palm and Tengvard 2011; Sovacool and Lakshmi Ratan 2012). About 26% of the new solar PV installations in Europe in 2017 were residential rooftop—i.e., small-scale prosumer—installations (Schamela et al. 2019). The total technical potential for residential solar rooftop installations in Europe was estimated to be ca. 240 GW in a study commissioned by the European Commission (2017). Furthermore, the CE Delft (Kampman et al. 2016) study estimates that the theoretical number of households producing energy in Europe could be as high as 113 million by 2050.

Drivers and barriers for prosumerism have been addressed in earlier studies (IEA-RETD 2014; Inderberg et al. 2016). IEA-RETD's (2014) report on residential solar prosumers, for example, summarizes these drivers as economic drivers, behavioral drivers, technology drivers, and national conditions. The growth of the prosumer base is constrained by, for example, high PV system costs, low electricity price level, low self-consumption ratio, low insolation, lack of trust in technology, and policy uncertainty (IEA-RETD 2014).

A sought-after economic benefit of installing solar PV is cost-saving, especially if the retail electricity price level is high and electricity is used for the heating and/or cooling of premises (Ruostetsaari et al. 2018). In addition to the retail electricity price, the cost savings from the distribution network operator's network tariffs and taxes are essential to the profitability of PVs. Despite the global decline in solar PV price, acquiring RETs for energy production still requires a substantial financial investment and hence the consumers have to consider the costs versus benefits of installing solar

PVs. The high upfront investment associated with solar PV has been suggested as one of the key barriers for solar PV adoption (Ruostetsaari et al. 2018; Scarpa and Willis 2010).

The economic performance of the solar PV system depends on the amount of sunlight (irradiation or insolation) received in the particular area. For example, Nordic countries have substantially less insolation than the countries located in the equatorial region. However, owing to its long daylight hours during summer, Finland has almost as good annual sun exposure as Germany. The insolation varies in Europe as well. Spain and Portugal, for example, have much higher insolation than Germany in the Northern Europe. The insolation does not, however, appear to have a clear connection to the prosumer base; prosumer base growth in Spain has plateaued owing to the disincentives of solar energy production, whereas the attractive remuneration incentives in Italy, Germany, and the UK have boosted the prosumer base growth (Kampman et al. 2016).

Indeed, it is widely argued that policy support is needed to increase the adoption of sustainable technologies. Policy support for solar power has certainly boosted its diffusion in markets such as UK and Germany (Campoccia et al. 2014; Ossenbrink 2017; Ramírez et al. 2017). Various policy incentives, such as investment support, government grants and loans, and tax exemptions, have been made available, but the introduction of FIT has been arguably one of the most effective policy instruments to boost residential solar PV adoption (Ossenbrink 2017). By now, both UK and Germany have started the FIT phase-out schemes that have affected the solar PV market growth (European Commission 2017). In Germany, the solar PV growth reached its peak in 2012 and started to decline after the FIT phase-out scheme was introduced (Wirth and Schneider 2016).

Prosumers and solar organizations have been influential in boosting the solar diffusion e.g. in Germany (Dewald and Truffer 2011, 2012; Jacobsson and Lauber 2006) and in the US (Noll et al. 2014). Consumer decision to invest in RETs is affected by not only the economic considerations, whether market-based or policy induced, but also other factors (Kotilainen, Valta, et al. 2017). For instance, the importance of pro-environmental attitudes (J. Palm and Tengvard 2011) have been studied in the context of energy prosumerism (Kalkbrenner and Roosen 2016; Poortinga et al. 2004; Sovacool and Blyth 2015). Likewise, individual factors, such as values, beliefs, and attitudes have been found to affect the investment decisions regarding solar PVs (J. Palm and Tengvard 2011).

2.2.2 Energy sales

Prosumers that have the ability to connect their production to the electricity grid can become sellers of energy. The regulation related to the grid connection and energy sales varies by country even within the European Union (EU). However, in most countries in Europe, small-scale prosumers are allowed to connect to the grid. In the developing countries, however, the electricity grid is not always available; hence, there are limitations to energy access and sales in many rural areas. Energy sales have been boosted by attractive tariff structures and other incentives and this has been increasing the overall adoption of RET in countries that offer these incentives.

One of the emerging trends in Europe, which is interesting from the energy sales perspective as well, is the rise of self-organizing energy communities (Kalkbrenner and Roosen 2016; Yves and Teufel 2017). The Clean Energy Package Article 22 of the Renewable Energy Directive addresses the renewable energy communities (European Commission 2017) with the purpose of enabling citizens and local authorities to invest in their own renewable energy production and to have fair participation in, for example, renewable energy tenders. The background of this directive is the observation that the involvement of small local actors is increasing the acceptance of larger renewable energy projects by the locals, hence offsetting some of the "not in my backyard" (NIMBY) barriers (Dronkers et al. 2016). Energy communities do not necessarily build their own distribution network but focus on investing in their own production, in most cases using solar PVs or wind turbines. The communities may also sell or share energy within the community or with the electricity grid. The regulation on energy communities is further developing and more legislative frameworks are being designed.

Energy communities can be either physical—e.g., micro-grid–based—or virtual, in which an aggregator bundles energy from multiple individual prosumers, EVs, or other resources to make up larger controlled entities. In this case, the community works as a virtual power plant (VPP) from the electricity market perspective. Novel business and energy market models are needed to support new types of energy sales. Sovacool and Parag (2016) proposed four basic prosumer-centric energy market typologies: peer-to-peer (P2P) model, prosumer-to-interconnected micro-grid, prosumer-to-islanded micro-grid, and organized prosumer groups.

Residential prosumers in same neighborhoods or in apartment blocks may form energy communities that can effectively be a micro-grid: that is, a physically limited part of the distribution grid (see Figure 5).

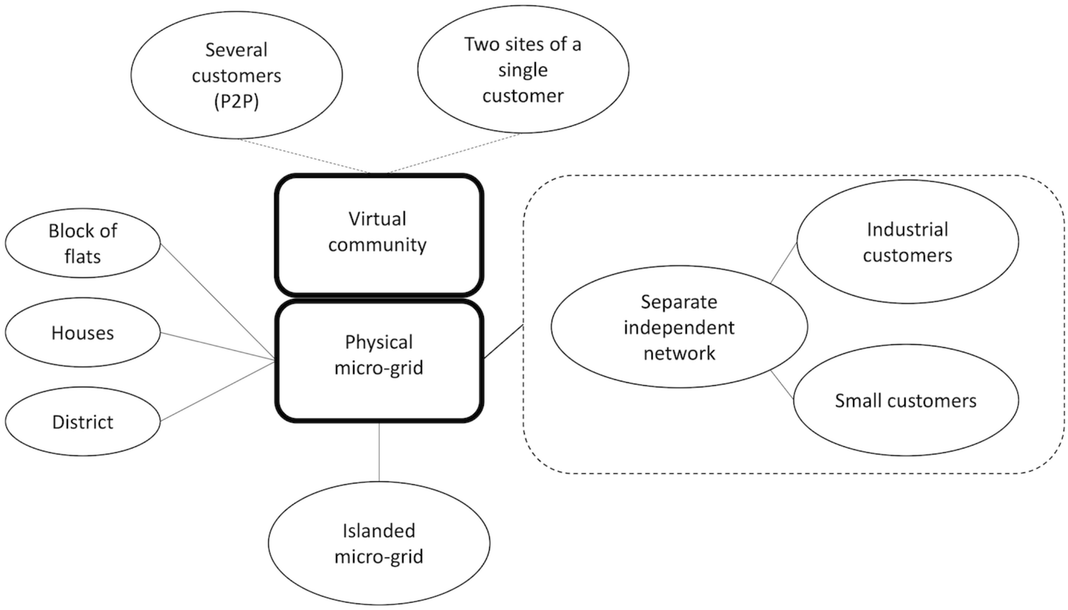

Figure 5. Types of micro-grids and their commercial connections to the (distribution system operator) DSO and energy market, adapted from (Järventausta et al. 2020).

The ongoing energy transition, combined with suitable regulation and market design, supports the emergence of grid-connected residential micro-grids by individual houses, blocks of flats, or districts in the European states. Some of the micro-grids could also potentially operate in islanded, or "off-grid", mode.

Independently operating micro-grids, with own industrial scale energy production, that serve larger industrial customers or smaller consumers, would require a separate license for operation as an independent network under the current market design in most European states. For example, an industrial micro-grid "LEMENE" is planning to pilot such operations in Finland pending the permission from the Energy Market Authority (Marjamäki 2019).

Virtual micro-grids represent the situation wherein production and consumption by either an individual prosumer or an organized prosumer group are in different physical locations. P2P energy sales in virtual communities are technically possible, but the current market mechanism and regulation still limit this activity (Morstyn et al. 2018). Aggregators are emerging actors that can facilitate prosumers to market models in energy markets (Iria et al. 2018). An aggregator gathers the distributed flexible resources and trades them in different electricity markets. Aggregation is needed for ensuring the balancing the demand and supply and to enable small-scale prosumers to participate in electricity markets. In the future, local markets may also exist to serve the needs of grid-level distribution networks, such as failures and local congestion management. Aggregator business models are developing but are not yet widely available in all markets (Mamounakis et al. 2015, 2017; Ottesen et al. 2016).

Energy sales, especially in virtual communities, emphasize the role of the information systems that enable remote and automated control (Pasetti et al. 2018). Digital platforms to enable energy sales are rapidly developing and can be utilized in different ways. Blockchain can be used as a technology enabler for P2P energy sales either in micro-grid–based energy communities or virtual communities (Kotilainen et al. 2019). Currently, there are multiple ongoing pilot installations and demonstrations using blockchain (Andoni, Robu, Flynn, Abram, Geach, Jenkins, Mccallum, et al. 2019; Casino et al. 2019); however, no conclusive evidence is obtained on whether blockchain is effective in organizing decentralized energy sales

2.2.3 Energy storage

For the ongoing energy transition, finding both technologically and economically feasible solutions for energy storage is important (Gallo et al. 2016). Batteries play a significant role in achieving power self-sufficiency. In some countries, PV and batteries alone could provide sufficient power for a prosumer or a micro-grid and could enhance the efficiency of solar PV energy generation at the national level.

One of the challenges of using solar PV is that energy is generated during the day when the residential consumption is low and feeding energy to the grid is not economically optimal owing to the typically lower day-time tariffs. If a battery is available, it can be charged during a low-tariff period and discharged in peak periods when the tariffs are high. The capability to store the energy generated during the day and use it when the demand is at its peak would be highly desirable from both economic and environmental (efficiency) viewpoints (Barbour and González 2018).

Home batteries are already commercially available but require further technical and economic improvements to be fully feasible for wide-spread use. Improvements in battery efficiency and production gradually make batteries more suitable to be used for energy production in small-scale installations. With the gradually maturing battery technology, storing energy at home is becoming feasible, but the price levels for battery storage are still too high to make it economically viable in smaller scale installations (Barbour and González 2018; Uddin et al. 2017). Also, safety considerations need to be addressed when placing battery storages in residential buildings.

Before the use of home batteries becomes economically viable, EVs may serve as residential energy storages. Solar rooftop panels can be used to sustainably charge EVs at the residence. The EV market has rapidly grown in recent years, especially in Norway, where EVs are heavily subsidized (IEA 2018). The global sales of EVs between 2010 and 2018 reached about five million units (IEA 2019).

The key adoption barriers for EVs include the lack of charging infrastructure and concerns of EV operating range ("range anxiety") (Kester et al. 2018). Charging infrastructure development and fast and smart charging technologies supported by public and private funding are necessary to enable the full exploitation of EVs (Lieven 2015). However, the high purchasing price of EVs is considered the main barrier for EV adoption, especially in markets where subsidies are not available. Policy analyses (Kotilainen et al. 2018; Kotilainen, Aalto, et al. 2019; Ruostetsaari et al. 2016) conducted in Finland and Nordic states, for example, found that economic factors have the highest influence on the decision to acquire an EV. Determined to electrify its transportation, Norway has been a front-runner in removing EV adoption barriers (Figenbaum 2017): battery electric vehicles (BEVs) are no more expensive than their ICE counterparts owing to substantial tax-exemptions, and EV drivers are given priorities when using public transportation lanes and opportunities for free-parking in city centers (Chaim et al. 2016).

2.2.4 Demand response

Residential sector energy consumption accounts for ca. 30%–40% of the energy demand globally; residential loads significantly influence the peak demand (Haider et al. 2016a). The electrical system has traditionally adapted to the fluctuations in consumption by adjusting the production by large power plants, such as hydropower. In the future, an increasing share of energy production will be variable production based on distributed RES, which means that the production capacity is becoming more difficult to predict and system flexibility needs to be increased. If the system is flexible, the requirement to build extra capacity to meet the peak consumption and production needs decreases. DR includes a wide variety of functions with varying importance and earning logic from the utility perspective. Earlier research have found that the regime players play a key role in initiating and orchestrating user participation in energy processes (Skjølsvold et al. 2018; Strengers 2014; Wallsten and Galis 2019). In DR, consumers and prosumers offer their energy loads to be controlled by DSO to provide reserve energy resources to the grid or market actors when needed, for example, from EV or battery storage. This could also simply involve turning off heating or the water tanks or any other controllable loads for a short period of time (Kubli et al. 2018).

Good visibility to energy consumption is needed by different stakeholders when participating in the flexibility markets. Automation systems for the energy management of homes and other real estate play an important role in increasing the demand elasticity. Smart meters can be used to monitor energy use. Smart meter ownership varies but it typically stays with utility whereas home energy management systems (HEMSs) are usually owned by end-users and give the user more control because in addition to measuring consumption and flows, the user can control and manage the local energy sources. Especially when combined with an electricity storage device, HEMS could offer a powerful value proposition for home owners to participate in DR (Shakeri et al. 2017). Lack of standardization and insufficient market rules hinder small-scale prosumers and consumers from actively participating in the energy markets (Valta et al. 2018). HEMS could enable more active participation in the energy markets for prosumers; however, currently, the market regulations still pose obstacles.

EVs have potential as flexible resources owing to their ability to be used at different physical locations, such as at home and workplace. EVs' potential in providing flexibility to the electricity market can be realized when smart charging or vehicle-to-grid (V2G) (Sovacool et al. 2017) types of business models start gaining momentum. EVs can be useful in electricity markets and DR schemes in at least three ways: as a controllable load that uses smart charging, as a power source for the electricity grid (V2G), or as a back-up power source at the place of residence (vehicle-to-home (V2H)).

DR has been in use for industry customers and while residential DR has been available e.g. in the US (Cappers et al. 2010) it is currently being tested and implemented in the residential sector in most markets. DR schemes can be based on tariff structures that motivate energy consumers to shift their energy use away from the peak usage periods before and after business hours. The two types of DR schemes are price-based and incentive-based schemes (B. Zhou et al. 2016). Time-of-use (TOU), critical peak pricing (CPP), and real-time-use (RTU) based tariff schemes have been introduced in several markets (B. Zhou et al. 2016). Other types of pricing schemes also exist. For example, in Finland some DSOs have introduced a power-based distribution tariff scheme for small customers to have a pricing model that better reflects the actual use of the distribution network (Honkapuro et al. 2017). The price-based schemes aim to shift the energy consumption away from the peak periods. Incentive-based schemes may use direct load control, interruptible loads, demand side bidding, emergency DR, or ancillary service programs (Iria et al. 2018).

In cases where the participation in the flexibility scheme requires behavioral change, the chances for voluntary participation are relatively low (Nolan and O'Malley 2015; Wijaya et al. 2014). Even monetary incentives are not widely accepted or understood (Annala et al. 2014; Haider et al. 2016b; Nolan and O'Malley 2015; Vanthournout et al. 2015). One reason for low interest levels in DR schemes may be that the benefits of participation are not clear for the consumers without real-life experience of the implications (Paterakis et al. 2017). With increased automation and remote control, DR can be implemented without homeowner involvement. In cases where the perceived comfort level is not affected, fully automated DR could be the answer to low interest toward DR.

2.2.5 Perspective one: prosumers as innovators

The fifth prosumer activity under observation is innovation engagement: The first *perspective* of this dissertation observes prosumers as innovators. Prosumers can play a role both as innovation adopters and as co-creators of innovations. This chapter provides an overview of these key concepts. Furthermore, the appended Articles III and IV study consumers and prosumers as innovators.

2.2.5.1 Prosumers as innovation adopters

Sustainable innovations only make an impact if they are commercially widely adopted, and consumers only become prosumers if they adopt RETs and start using them. For the prosumer base to grow, different types of technologies that enable energy production, sales, storage, and flexibility need to be adopted by a large group of consumers. Diffusion of solar PVs, EVs, and batteries have been studied (Barbour and González 2018; Langbroek et al. 2016; Wolske et al. 2017), but more research on the innovation diffusion of household RETs is still called for in Europe (Heiskanen et al. 2018; Heiskanen and Matschoss 2017).

Diffusion of innovations

Diffusion of innovations theory focuses on understanding how an innovative product gains momentum and diffuses through population over time (Rogers 1962). The innovation is typically adopted by different adopter groups sequentially. The adoption initially starts from *innovators* and *early adopters* and progresses to *early majority*, *late majority*, and the *laggards*. As diffusion progresses from one adopter category to the next, the characteristics of the adopters and their decision-making criteria change. The innovators play a critical role in the diffusion. These technology enthusiasts are interested in trying out new solutions despite potential quality issues and higher costs. Next come the early adopters that also tolerate immature solutions and are typically keen on acting as opinion leaders in their social circles; hence, they play an important role in promoting new solutions to the later adopter groups. (Rogers 1962) These early market adopters bring the innovation across the "chasm" that Moore (G. A. Moore 1991) identified between the early adopters and the early majority, the group that will boost the mass market acceptance of the product or service by adopting it. The chasm is a similar concept to the "valley of death" in which majority of the innovations fail during the research and development process (Markham et al. 2010). The early majority adopters, however, only accept solutions that provide concrete value and are reasonably priced. The highly price-sensitive late majority and laggards finally follow the other adopter groups, and their decisions are dependent on peer recommendations (Kotilainen, Jarventausta, et al. 2016). For instance, peer effects on the solar diffusion have been studied widely (Bollinger and Gillingham 2012; Müller and Rode 2013; A. Palm 2017; Rai et al. 2016)

Rogers (1995) proposed that the consumer acceptance of a new technology involves several stages: knowledge, persuasion, decision, implementation, and confirmation (Rogers 2003). Valta (Valta 2017) studied energy prosumers' journey through these stages and found several bottlenecks in the current market conditions that may prevent the adoption of RETs. For example, smart meter diffusion depends on the availability of a DR market that would provide incentives for its adoption. If no such market exist, diffusion of smart meters is slower (Valta 2017).

The persuasion stage of the consumer journey is especially interesting as it affects the consumer decision to either adopt or reject a RET. Rogers (Rogers 2003) identifies five features that affect persuasion: relative advantage, compatibility, complexity, trialability, and observability. Relative advantage refers to the perceived net benefits of a novel solution. McDaniel and McLaughlin (2009) propose that concerns over data privacy could influence the perceived relative advantage of RET. Compatibility determines how the innovation matches one's normal, everyday way of doing things. Compatibility may be decreased, for example, in case a behavioral change is required. Some of the compatibility issues could be overcome by offering price incentives that could compensate for the need for behavioral change (Benders et al. 2006). Complexity may also influence adoption; complex products have been found to have longer diffusion times (Rogers 1995). In particular, the later adopter groups appreciate ease of use whereas the early adopters can better tolerate complexity (Rogers 1995). Being able to try the new solutions is important particularly for innovators and early adopters as they like to play around with new solutions (Rogers 1995). Later market adopters typically expect peer recommendations before making purchase decisions, making observability an important factor in their decision making (Rogers 1995).

Behavioral aspects of technology acceptance of RET

Up-front investment in RETs is required to get started as a prosumer. Hence, the role of economic factors is often emphasized in consumer decision-making. Other factors, besides financial costs and incentives, however, have been found to affect the consumer adoption of RETs. In another prosumer-related research (Kotilainen, Valta, et al. 2017), we find that the research on active consumers and consumer decision-making is multi-disciplinary, and research approaches encompass at least rational economic models , behavioral economics, sociology, psychology, and technology adoption and diffusion models. The traditional economics' approach assumes consumers to optimize their resources and make rational decisions. However, this type of rationalist assumption is widely considered an oversimplification (Simon 2011).

Environmentally sustainable behavior in many cases requires behavioral change, and the complexity of behavioral change is widely acknowledged in research (Allcott and Mullainathan 2010; Frederiks et al. 2015; Kotilainen, Valta, et al. 2017; Masini and Menichetti 2013). Balcombe et al. (2013) indicate that at least the factors related to finance, environment, security of supply, uncertainty, trust, inconvenience, and impact on residence affect the consumer decision to adopt microgeneration technologies. The sociological approach to understanding pro-environmental behavior includes theories such as the value-belief-norm (VBN) theory (Stern et al. 1999), theory of reasoned action (TRA) (Fishbein and Ajzen 1975), and theory of planned behavior (TPB) (Ajzen 1985). The key elements of these theories are related to the beliefs, norms, and attitudes that may predict pro-environmental behavior (Kotilainen, Saari, et al. 2019).

One research focus indeed has been on pro-environmental values as a predictor of adopting sustainable innovations (Huijts et al. 2012; Schelly 2014; Wolske et al. 2017). Some of these "green users" that have an interest in sustainable innovations (Akehurst et al. 2012) have been identified as the early adopters that may promote sustainable innovations to their peers (Nygren et al. 2015). However, contrasting results from earlier research suggest that pro-environmental attitudes do not necessarily predict pro-environmental behavior (Kennedy et al. 2009; Pickett-Baker and Ozaki 2008). Behavioral prediction models have received criticisms on the lack of evidence regarding attitudes being effective determinants of the actual behavior; in fact, earlier research has proposed several gaps between attitudes, intentions, and behaviors (Courtenay-Hall and Rogers 2002; Kennedy et al. 2009; Kollmuss and Agyeman 2002; Sheeran and Abraham 2003).

Based on VBN, TRA, and TPB, the technology acceptance model (TAM) (Davis 1989; Davis et al. 1992) proposes "perceived usefulness" and "perceived ease of use" as the predictors of attitudes toward accepting a novel technology as well as the intentions to use it. TAM has since been further developed into a more comprehensive model called unified theory of acceptance and use of technology (UTAUT), combining even more elements from the earlier discussed behavioral theories (Venkatesh et al. 2017). TAM has been widely used in the context of information systems (IS) in organizations (Chau and Hu 2002; Davis 1985; Ha and Stoel 2009; Lu et al. 2003). More recently, TAM applicability has been tested in the context of health technologies (Ketikidis et al. 2012), and studies related to energy technologies (Alam et al. 2014; Broman Toft et al. 2014; Chin and Lin 2016; Naspetti et al. 2017). TAM is used in the appended Article V to explore how different policies (as external factors) might influence consumers' interest toward accepting RETs.

2.2.5.2 Prosumers as co-creators of innovations

There are high expectations for innovative solutions that support the sustainability transition toward a low-carbon energy system (IRENA, 2018). The energy sector has been a challenging sector for innovations. Dominated by powerful incumbents and limited by national and international regulation, this sector poses many obstacles for new entrants (Wustenhagen and Wuebker 2011). Energy transition based on digitalization, decentralization, and de-regulation has already changed the energy sector toward a more innovation-friendly environment (Astarloa et al. 2017). Smart grids can move energy flows bi-directionally, which creates a need for developing applications and services for managing the energy flows and data (Järventausta 2015). New entrants from the information and communications technology (ICT) industry to the energy sector fulfil this need. A systemic approach is required to develop this type of services and solutions and multiple stakeholders, including end-users, need to be involved (Bigerna et al. 2016; Hyysalo et al. 2017). Recent research suggests that the different stakeholders need to find ways to co-operate and create impactful sustainable innovations (Aquilani et al. 2018; Kruger et al. 2018). The notion of consumers and prosumers as innovators is not entirely new as several studies exist (Heiskanen and Matschoss 2011, 2016, 2017; Hyysalo et al. 2013; Matschoss et al. 2015), but continuous developments in the energy sector open more and more opportunities for engaging and collaborating.

The notion of innovation has developed from an internally focused activity toward a more externally oriented approach. *Open innovation* means seeking innovations outside the firm's boundaries, where the bulk of the knowledge lies, and innovating with external stakeholders such as suppliers and partners; Chesbrough (2003, p. xxiv) first coined open innovation and describes it as "a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology." Open innovation can be effective in the development of novel products and services for either existing or new markets (Chesbrough 2003). Different levels and modes of openness are typical for open innovation; innovation can also be semi-open, wherein some of the required new knowledge is created in close interaction with other actors (Rocha et al. 2018).

This type of *co-innovation* is an activity that stretches stakeholder involvement and interaction even further and beyond "openness" (Lee et al. 2012): here, there are multiple stakeholders collaborating toward a common goal while concurrently competing with one another (Nachira et al. 2007). Co-innovation can be relevant for creating and delivering systemic solutions for renewable energy offerings (Leydesdorff 2012; Tsoutsos and Stamboulis 2005).

Co-creation is a concept in which companies and their customers collaborate to ideate or create solutions of mutual value (Prahalad and Ramaswamy 2004). Co-creation is typically systemic (Nielsen et al. 2016). Another popular notion, *crowdsourcing*, first introduced by Jeff Howe (Howe 2006), could be seen as a sub-category of co-creation. Whereas co-creation focuses on individuals that may have specialized technology skills or development ideas, crowdsourcing is mainly used for sourcing ideas from large groups of people through digital platforms (Bartl et al. 2010). Co-creation with end-users is also called *user-centric innovation* or *lead-user innovation* (Ornetzeder and Rohracher 2006, 2013; von Hippel 2005; Von Hippel 2005). Von Hippel (von Hippel 1986) describes lead-users as advanced early adopters with technical skills.

Co-development refers to the design and development activities related to either hardware or software development processes. For instance, a solar HEMS manufacturer could outsource part of the software development to technically advanced individuals by providing development toolkits and a virtual development environment. Co-creation activities can include feedback collection, lead-users' co-operation in ideation or development, providing toolkits and digital platforms for virtual co-creation, and end-user involvement in testing at either the pre-launch or the commercial phase (Füller 2010;Kotilainen et al. 2016; Nambisan 2010; Piller and Walcher 2006; Prahalad and Ramaswamy 2004).The collaboration with end-users may take place in any of the new product development (NPD) process stages: pre-NPD, development, demonstrations, and commercialization (Cooper 2014). Furthermore, the co-creation process can be either reactive or proactive (Kristensson et al. 1991).

Besides company-driven co-creation, some individuals independently innovate owing to the lack of desired products, the need for certain functionality, and the need for customized solutions. For example, different types of energy communities are currently emerging and are envisioned as fruitful arenas for *grassroots innovations* (Klein and Coffey 2016). These include both virtual communities and micro-grid communities defined by the physical proximity of community members (Mamounakis et al. 2015; Morstyn et al. 2018; Pasetti et al. 2018). *Do-it-yourself* (DIY) users typically encompass some level of technical know-how (Cloutier et al. 2018; Fox 2014; Nesti 2018). They often actively participate in discussion forums and virtual co-creation or use open source software (OSS) to exchange ideas, develop solutions, and modify ready-made products or to provide suppliers with feedback and requirements (Kotilainen, Saari, et al. 2019).

Co-creation and end-user innovation can take place in different forums: virtual platforms, living labs, crowdsourcing projects, or prosumer communities, collectively called as co-creation milieus (Bergvall-Kåreborn et al. 2009). Virtual co-creation is particularly useful in the development of software with technically expert users either based on OSS or the firm's proprietary platform (Feller and Fitzgerald 2000; Nambisan 2010). Living labs are open innovation milieus, for example, taking place in the context of Smart City development. Here the users are observed as they utilize novel solutions and their ideas are collected for improving the solutions (Leminen et al. 2012; Pallot et al. 2010). Crowdsourcing projects (Boudreau and Lakhani, Karim 2013) often focus on idea sourcing from end-users. Prosumer virtual communities are energy communities that operate as VPPs (Rathnayaka et al. 2011; Wainstein et al. 2017). Energy communities have been suggested as potential milieus for powerful grassroots innovations that could influence the entire energy transition (Hossain 2016; Juntunen 2014; Klein and Coffey 2016; Seyfang and Haxeltine 2012).

Why do end-users then engage in the co-creation of RET innovations? Appended Articles III and IV focus on exploring this question. In short, user motivation to co-create activities depends on external and internal conditions, competences, and underlying motivations (Kotilainen, Mäkinen, et al. 2016). Ryan and Deci (Ryan and Deci 2000) identify two types of motivations, intrinsic and extrinsic, in their self-determination theory. Intrinsic motivation is based on the perceived value of the activity itself. It is proposed as the mechanism explaining the spontaneous exploratory behaviors observed in humans (Berlyne 1966). Earlier research have proposed several examples of intrinsic motivations, including uncovering new things, interest in technologies, enjoyment, gaining knowledge, engaging in challenges, competence feedback, establishing peer relationships, curiosity, self-expression, and receiving approval (Agarwal and Karahanna 2000; Lowry et al. 2013; Ryan et al. 2006; Yee 2006). Extrinsic motivation means motivation based on a preferred result of an activity. Rewards such as financial gains, status, or admiration may be such results. Wolf and McQuitty (2011) propose that end-user innovators are extrinsically motivated to fix issues related to missing functionality or poor quality or are in need of customized solutions. Participating in challenges and competitions may also be seen as an extrinsically motivated activity.

Co-creation is also closely linked to creativity. Amabile (Amabile 1996) finds intrinsic motivations be central for creativity. Füller (2010) proposes a set of motivations, most of which are intrinsic, that are closely related to co-creation. Nyborg and Ropke (2013) suggest that energy production and co-creation of energy solutions are influenced by the feeling of empowerment, learning, curiosity, positive feedback, and interest in technology.

One of the challenges in engaging consumers and prosumers in the current energy market situations is the somewhat poor reputation of electricity utilities that are famous for increasing prices and fees. Lack of trust in the utilities may hinder mutually beneficial collaboration (Gangale et al. 2013; Stenner et al. 2017).

2.2.5.3 Innovation ecosystems

As the energy system is gradually more influenced by actors from other industries, such as ICT, transportation, and built environment, it begins resembling an ecosystem. This sector coupling poses new requirements for more coordinated multi-party co-operation in the forming ecosystems.

Several types of ecosystems have been identified in research: innovation ecosystem (e.g., (Adner 2006; Oh et al. 2016; Wessner 2005), business ecosystem (e.g.,(J. Moore 1996; J. F. Moore 1993)), and digital business ecosystem (e.g., (Nachira et al. 2007)). In open ecosystems (Lee et al. 2012), different stakeholders collaborate and produce solutions. Ecosystems based on open innovation have some distinctive features; they are systemic, requiring aligned participation and contribution from multiple actors, are based on digitalization, are market-driven, and have decentralized governance (Oh et al. 2016). Appended articles in this study focus mostly on *innovation ecosystems*. Innovation ecosystems have been studied rather widely (Adner 2006, 2017; Dedehayir et al. 2018; Oh et al. 2016) and multiple definitions exist. An example of an innovation ecosystem is "Smart Otaniemi" in Finland (https://smartotaniemi.fi), in which multiple companies develop and integrate systemic solutions on smart mobility, local flexibility, building-level intelligence platforms, connectivity, and enabling technologies. More generally, such innovation ecosystems are developing around smart grid technologies at different locations. In time, these innovation ecosystems further evolve into business ecosystems (Oh et al. 2016).

A very important feature of ecosystem innovations is their systemic nature; hence, they are highly dependent on other stakeholders inputs (Adner 2006). An ecosystem's value is the sum of its stakeholders contributions (Talmar et al. 2018). Talmar et al. (2018) synthesize an intra-actor role in ecosystem value creation by introducing an intra-actor relationship mapping wherein actors, resources, activities, value contributions, and ecosystem value proposition are identified (see Figure 6).

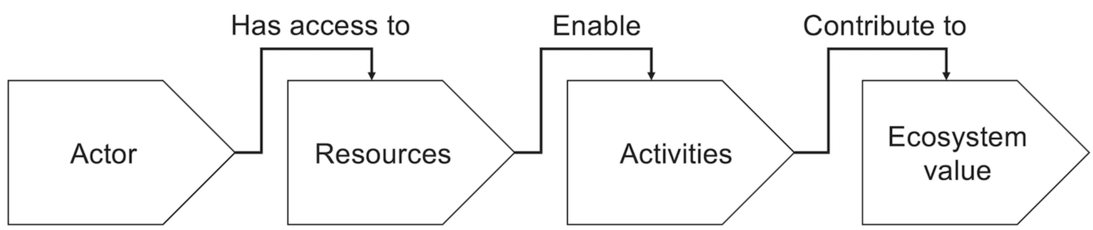

Figure 6. Figure 6. Intra-actor role in ecosystem value formation, adapted from (Talmar et al. 2018).

Prosumers are such actors in the smart grid innovation ecosystem, and they may participate in various ways in value co-creation. Appended Article II especially focuses on understanding the prosumer role in this context. Hyysalo et al. (2013) studied end-user innovations related to heat-pump and wood-pellet burning systems in Finland and suggest that the role of inventive users is important in both the technical evaluation of and market creation for new technologies. End-user and

RET-focused energy innovation research exists but is limited (Kubli et al. 2018; Olkkonen et al. 2017; Ornetzeder and Rohracher 2006). Users and prosumers can actively participate in innovation co-creation, either with companies or by themselves (Nielsen et al. 2016). The role of grassroots innovations emerging from, for example, energy communities is recognized as important from the sustainability transition viewpoint (Köhler et al. 2019; Korjonen-Kuusipuro et al. 2017). Similarly, sustainable end-user innovations (SEI) can produce novel solutions and increase the bottom-up contributions to sustainability (Nielsen et al. 2016).

2.2.6 Perspective two: policy as an enabler

The second perspective of this dissertation explores policy as an enabler for the consumer-to-prosumer evolution. Understanding the policy role in sustainability transition is one of the key tasks in sustainability transition research (Markard et al. 2012). Policies are needed to steer the transition onto the preferred path to overcome system and market failures (Weber and Rohracher 2012). It is also argued that effective policy mixes can accelerate the transition (Kern and Rogge 2016; Kotilainen, Aalto, et al. 2019). Examples from countries, such and the UK and Germany, applying policy incentives such as FIT show that policies can be highly effective in accelerating prosumerism through the adoption of RETs. On the contrary, policy intervention has been criticized for distorting market mechanisms and giving unfair advantage to certain technologies (Pegels and Lütkenhorst 2014). Nevertheless, in cases wherein increasing prosumerism is considered desirable, public policies certainly are useful. Rogge and Reichardt (2016) propose a research agenda for policy in sustainability transitions and call for more systemic and holistic policy mixes that combine both the policy instruments and processes. Next, I review the basic concepts of policy-making.

The main focus of this dissertation in terms of policy is the policy instruments and policy mixes affecting consumers and prosumers. However, this chapter first gives a brief overview of policy process because of its importance for designing the policy mix (e.g., (Rogge and Reichardt 2016). This also allows for some discussion on the possibilities of prosumers to participate in and influence the policy setting. Citizen involvement in policy-making has been studied from different perspectives (Granier and Kudo 2016; Kraft and Clary 1991; Michels and De Graaf 2017; Szulecki 2018). However, the policy process is typically dominated by politicians and powerful companies (Ruostetsaari 2010).

The policy setting process, or policy cycle, typically includes the following phases: agenda setting, policy formulation, decision-making, policy implementation, and policy evaluation (Howlett and Ramesh 2003) (see Figure 7).

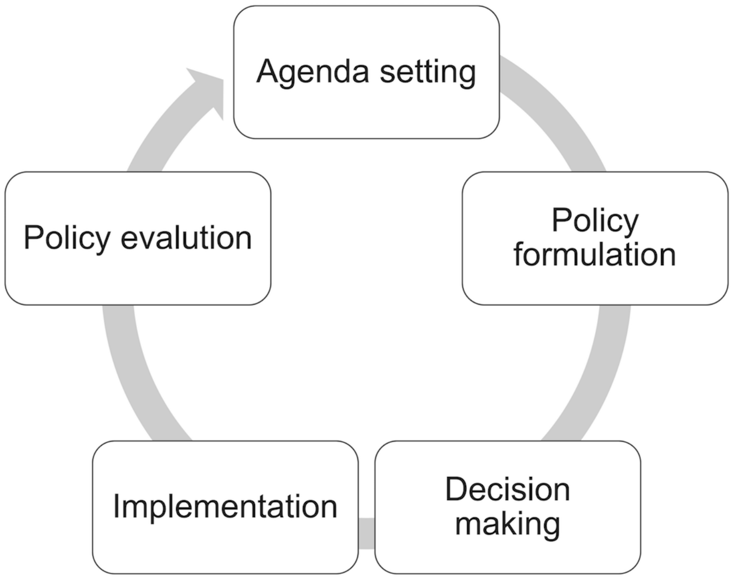

Figure 7. Policy cycle based on Howlett and Ramesh (2003).

The agenda setting phase determines the issues that receive political attention. In recent years, sustainability of the energy and transportation systems has been one of the key topics on the national and international political agenda. In Europe, EU strongly influences the national agenda setting in the member states. Policymakers as well as private and public actors play an important role during the agenda setting phase. Different theoretical frameworks are associated with this phase: for example, the agenda setting theory focusing on media influence on the public agenda setting by McCombs and Shaw (1993). Some actors and groups are more influential than others in policy-making. Relatively few people in key positions in government, industry, academia, media, and other institutions control a disproportionate share of the nation's economic and political resources (Ruostetsaari 2010). For example, in Finland, the energy policy setting has been highly influenced by large energy companies whereas the citizens have had limited possibilities to voice their opinions (Ruostetsaari 2010). Baumgartber and Jones (2010) propose that it is possible for less powerful groups to participate in and influence policy debates when the powerful groups lose their control of the agenda. Here, active energy citizens, or user-citizens as Schot et al. call them (Schot et al. 2016), have potential to influence the policy agendas. When a topic receives more attention, it typically increases negative public attitudes toward the status quo, enabling changes in the institutional structures.

The policy formulation phase outlines the solutions for the problems on the agenda. Possible ways of dealing with the problem are narrowed down and their benefits, costs, and potential externalities are discussed (Cochran and Malone 1999). Besides the policy design, policy tools are crafted for more specific identified options to address the problem. At this stage, input and advice is sought from different stakeholders, such as internal governmental sources or external stakeholders, through so-called policy advisory systems (Craft and Howlett 2012). However, the policy formulation phase has less participants than in the agenda setting and more work is done "outside the public eye" (Fisher et al. 2006).

Policy decision-making can be based on multiple standards, such as welfare maximization, public choice, multi-agent simulation, decision support, or public participation. Public choice is a microeconomic approach based on individual interest and democratic choices: the greatest good for the greatest numbers. Public participation is a more collective decision-making procedure that allows multiple stakeholders to be involved in the process, but it can be challenging as the stakeholders may not have equal power and networks to be influential (Fisher et al. 2006).

Policy implementation and adoption follow the decision-making phase. Formal institutions play an important role here. Policy implementation includes specifying policy programs and allocating resources and decisions. The implementation phase is considered critical for the success of the policy, and the instrument and policy mixes are designed at this stage. There are different approaches for implementation such as top-down, bottom-up, and hybrid, all of which have their own supporters (Fisher et al. 2006). Finally, the policy evaluation phase assesses the effectiveness of the implemented policy and utilizes the learnings in the next phase of agenda setting.

From the prosumer point of view, participation and influence in the policy process can take place in several stages. However, citizens are most active in the agenda setting and policy formulation stages.

In Europe, EU Directives steer the development of national agendas and policy targets. EC has launched several initiatives that define the "active consumer" role as part of the energy system and market (European commission 2016). While prosumers receive better acknowledgement, how prosumer-related policies are implemented greatly varies across the member states. The current focus of EU has shift toward ensuring that energy communities and aggregators are defined and their operational enablers are in place (European Commission 2017).

One challenge from the prosumer point of view is that the policies affecting them are created by multiple sources (Kotilainen et al. 2018; Valta 2017). A holistic approach to steering the development of multiple enablers and activities related to "prosumerism" seems to be lacking in most markets (IEA-RETD 2014), leading to the lack of policy mixes that systematically address multiple prosumer enablers and activities. In practice, the policies that affect prosumers are results of policy-making in multiple streams: industrial policy (including energy policy), innovation policy, environmental policy, and transition policy.

Industrial policy strives for the nation's economic growth (Aiginger 2007). Energy policy is typically considered as industrial policy. Incumbent strategic industries generally have a strong influence on the industrial policy as they hold access to critical resources for the economic and social well-being. These industries receive subsidies and tax exemptions to sustain and grow. For example, subsidies to fossil fuel–based industries are still granted in large quantities, despite the efforts to electrify transport and move toward renewable energy (Hyyrynen 2013). This in turn creates path-dependencies and lock-in existing systems, infrastructure, and process, thus slowing down the transition (G. G. Unruh 2000). It has been suggested that more strict regulative action should take place to destabilize the existing regimes, for example, by banning cars using diesel fuel (Rogge and Johnstone 2017a).

Traditionally, the *innovation policy* goal has been to boost national competitiveness and economic growth. However, more recently, sustainability and societal goals are emerging in innovation policy agendas. Furthermore, a more integrated approach to industrial policy and innovation policy has been suggested to support systemic innovations (Oughton et al. 2002). Innovation policies typically target the R&D phase and commercialization of technologies, but they also cover university research, intellectual property rights, and support for businesses. Innovation policies for sustainability aim to support the development and adoption of sustainably desirable technologies. The two basic approaches to innovation policy are technology push and demand pull (Grubb 2004). Technology push policies are more focused on supporting the development phase of technologies via R&D support, grants, demonstrations, investment subsidies, and tax exemptions (Bürer and Wüstenhagen 2009). Demand pull, on the contrary, focuses on supporting the commercialization of technologies before they become self-sustaining and competitive in the markets via more mature solutions. Examples of market-based policies are FIT, support for standardization, public procurement, and tax credits (Rogge and Rechardt 2013).

Moreover, innovation processes such as co-creation can be supported through policies. Systemic policies that support ecosystem-level activities include those providing platforms for experimenting and learning (Smits and Kuhlmann 2004).

Environmental policy defers from industrial and innovation policies that focus on ensuring national competitiveness and economic growth; its focus is on ensuring environmentally sustainable development through reducing pollution and emissions and supporting sustainable technologies and industries. Environmental policy instruments can be categorized in multiple ways; the most typical typology (Vedung 1998) divides public policies in three main types: command-and-control, economic, and soft instruments.

Command-and-control instruments encompass regulations such as carbon emission restrictions, restrictions on certain types of vehicles, technology and performance standards, FITs, and tradable certificates. Regulation either supports or prevents the potential engagement of consumers and prosumers in the energy system. Supporting examples of such regulation can be found in the case of EVs in Norway (IEA 2018), where EV users can utilize public transportation lanes and drive in the emission free zones in cities. Smart metering is another example of command-and-control policy; it has been mandated on the EC level, even though national implementation approaches vary. On the contrary, regulation may be argued to lag behind in enabling sustainable business models (Laukkanen and Patala 2014).

Economic instruments include emission trading schemes, public investments, tax credits, public funding, and subsidies. Economic incentives can be highly effective in boosting the adoption phase of RETs and EVs. Dynamic tariff structures, tax exemptions, subsidies, grants, and loans are examples of incentives that increase RET adoption. Full tax exemptions in Norway, for example, have accelerated the sales of BEVs, which cost the same or even a little less than their ICE counterparts. Denmark also applied tax exemptions on EVs but have already started to remove them, causing EV sales to almost halt (Kester et al. 2018; Kotilainen et al. 2018).

Soft instruments include, for example, education and information campaigns or voluntary approaches as well as management and planning instruments (Gunningham 2013; OECD 2001; Valta 2017; Vedung 1998). Information dissemination and education increase awareness and knowledge, which is the first step in the consumer journey to adopt new technologies (Rogers 2003). Soft instruments can be more effective as complementary to other types of policies and in supporting activities that require behavioral change.

The *transition policy* approach (Rene Kemp et al. 2007; René Kemp et al. 2007; Rogge and Johnstone 2017b; J Rotmans et al. 2001) to the policy mixes in sustainability transitions can be implemented in different ways. Policies can be used as instruments for de-stabilizing regimes or creating new niches. The destructive recreation of incumbent systems, or creative destruction approach (Johnstone et al. 2017; Schumpeter 1942), could be used to quickly de-stabilize the regime (Kivimaa and Kern 2015; Turnheim and Geels 2012). Path-creation aims to enable desired changes by introducing, for example, attractive innovation policies to support the development or demonstration of sustainable solutions. Once set in progress, policies typically evolve through drift, layering, conversion, and replacement (Beland 2007). In drift, new goals are set but old instruments remain in use. In conversion, new policies are introduced but old targets are maintained. In layering, new instruments and goals complement the old ones. Replacement introduces both new goals and policies (Kotilainen, Aalto, et al. 2019). Figure 8 summarizes the influence of different policy fields on the energy prosumers.

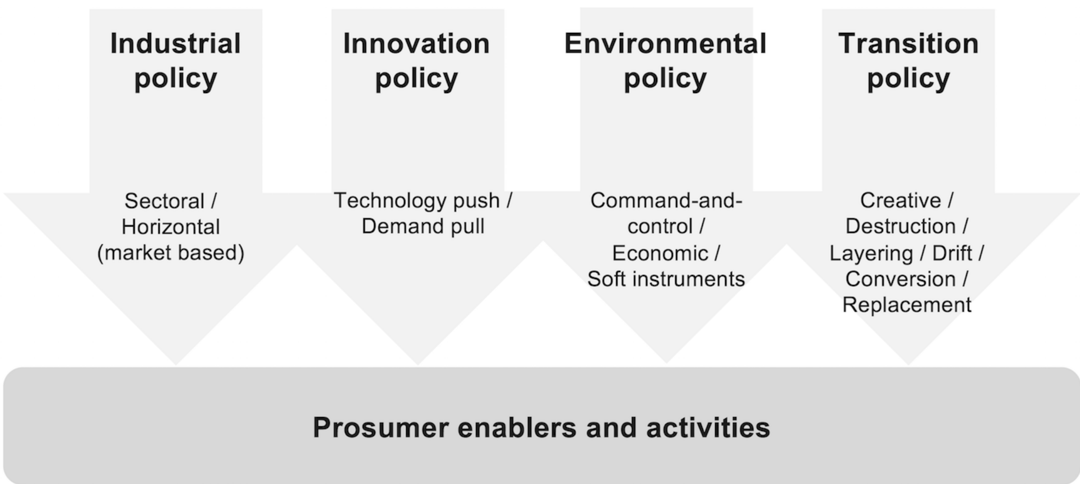

Figure 8. Policy influence on prosumers, adapted from (Valta, 2017).

2.3 Prosumers in transition

Energy transition is sometimes summarized as decentralization, digitalization, decarbonization, and democratization (4D) (e.g., (Nolden 2019), in which digitalization and decentralization enable environmental value through decarbonization and social value through democratization. Prosumers have emerged as part of the transition, and their role is evolving as the transition progresses. This chapter reviews the background and key theories related to the sustainability transitions and discusses the prosumer role in this context.

2.3.1 Prosumers in the energy system and transition

Growing number of prosumers can influence the future of energy systems and markets. Energy prosumption can positively contribute to the environmental, economic, and social aspects of sustainable development (Kotilainen 2019). From the energy system perspective, growing numbers of prosumers pose both opportunities (Brandoni et al. 2014) and threats to the current electricity system in which energy generation is centralized with predictable outputs (IEA-RETD 2014). Prosumerism increases the use of distributed energy resources (DER), which means more variable energy sources in the system, thus posing challenges to the system stability, predictability, and balancing. Electricity systems need to stay balanced in terms of production and consumption at all times; thus, good predictability is important. The inherently intermittent supply of RES makes RES-based systems difficult to predict (Blume 2007). Besides forecasting and capacity management challenges, growing prosumer base can create technical problems and quality and reliability issues related to e.g. over-voltage conditions, congestion issues, and stability issues (IEA-RETD 2014). Once the system becomes more reliant on variable energy sources, increasing the system flexibility becomes critical (Kiviluoma et al. 2018). Here, the prosumers that engage in DR schemes can contribute to the flexibility and load balancing of the grid. Furthermore, data privacy and security concerns emerge as a result of large quantities of collected, transferred, and analyzed data (Camek et al. 2013).

Besides technical challenges, commercial issues are bound to arise. First, incumbent companies' role is changing as new entrants enter the energy sector, and it is clear that this game will have both winners and losers. If off grid -prosumerism become more mainstream, the number of customers paying for the utilities will decrease, which in turn could lead to energy tariff increases for the rest of the end-users. This would cause more incentives for self-generation and eventually lead to a "utility death spiral" (e.g., (Laws et al. 2017). If prosumerism affects energy rates, "normal" consumers will face the highest impact (Eid et al. 2014). There are ethical concerns over a potential rift between those who can and cannot afford to self-generate energy. Furthermore, spillover effects such as decreased tax incomes would affect the national economy.

The different research approaches to studying energy transition include e.g. the following: a) the techno-economic perspective, where energy flows of production and consumption as well as energy markets are in focus; b) the socio-technical perspective centered around knowledge, practices, and networks; c) a political system perspective that focuses on policies and their influence on transformation (Cherp et al. 2018). In this dissertation, I do not strictly limit myself to any of these perspectives. I investigate energy transition as an example of sustainability transition; this research field deserves research attention from the theoretical point of view.

Research in the field of sustainability transition has become increasingly popular during recent years. According to the literature (Köhler et al. 2019; Markard et al. 2012; Pesch 2015), MLP, strategic niche management (SNM), transition management (TM), and technological innovation systems (TIS) can be regarded as the key theoretical frameworks applied in this field. Next, the key literature related to the theories are reviewed and discussed in the context of energy transitions and energy prosumers.

2.3.2 Socio-technical multi-level perspective and strategic niche management

Energy system sustainability transition induces multiple changes in technology, business, and *society*. *Socio-technical MLP* is a widely used framework for modeling sustainability transitions. The socio-technical MLP (Geels 2002; R. Kemp and Rip 1998) argues that transitions are the results of a dynamic process between different levels of the socio-technical system: niche, regime, and landscape. The main interaction takes place between niche actors on the micro level and incumbent actors of the socio-technical regimes on the meso level. Landscape on the macro level forms the layer that represents the society in terms of deeper values and beliefs. Niches are considered as "protected spaces" where radical innovations are developed and nurtured (R. Kemp and Rip 1998). Some of the important notions for the multi-level framework are path dependence and lock-in (Foxon 2002; Pierson 2000). *Lock-in* refers to a system becoming self-reinforcing. Lock-in has been defined as increasing returns derived from adoption of a certain technology giving incumbent technologies an advantage over new entrants (Arthur 1994). Lock-in typically causes *path-dependency*, which limits the feasible actions for the stakeholders. The concepts of lock-in and path-dependence explain why large-scale sociotechnical systems, such as the energy system, become embedded in society (Fouquet 2016; Klitkou et al.

2015; Kotilainen, Aalto, et al. 2019; Lovio et al. 2011). In energy systems, substantial volumes of different resources, such as labor and capital, become embedded into particular institutional formations (Scrase and Mackerron 2009). Strong path dependencies like this can apply lasting impacts on the sociotechnical systems. This in turn causes inertia, under which it becomes very difficult to re-orient the particular type of path dependent evolvement (Knox-Hayes 2012; Kotilainen, Aalto, et al. 2019).

Regime stability is furthermore enforced by the incumbent actors that have resources to resist the change (Geels 2014; Markard and Truffer 2008). The long techno-economic lifecycle and capital intensity of the energy system components likely contribute at the regime level to the inertia of the existing operators. In the ICT industry, however, the lifecycles are significantly shorter, allowing for faster industry changes. Like many incumbent energy companies, some of the key ICT companies entering the energy sector are also large and powerful. Transition scholars have engaged in studies concerning implications of the ICT sector into the energy sector (Erlinghagen and Markard 2012; Markard 2018). Figure 9 depicts the transition of regimes in the context of the MLP.

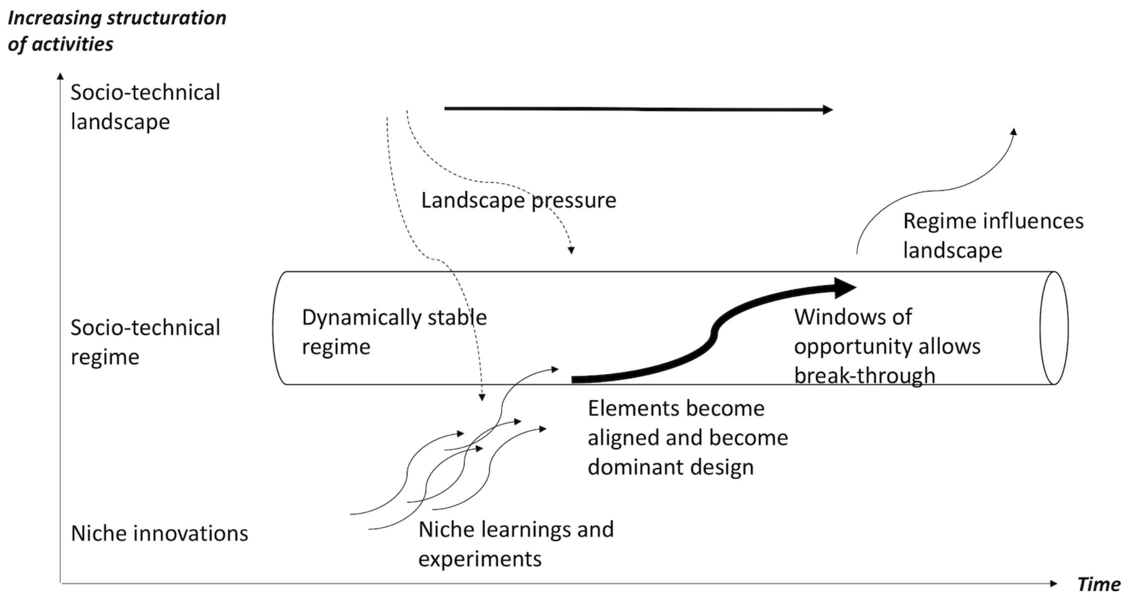

Figure 9. Figure 9. Multi-level perspective on transition, adapted from (Geels, 2012).

As the energy transition is influenced by the existing system's stability and lock-in the transition process is not easy and predicting exactly where it will lead is difficult. Based on Geels and Schot's (Geels and Schot 2007) earlier work, Verbong and Geels

(2010) laid out three transformation pathways for the electricity system until 2050: "transformation," "de-alignment–re-alignment," and "reconfiguration". Of these, the de-alignment–re-alignment pathway is interesting from the prosumer point of view because it envisions a breakthrough of DERs. In this set-up, numerous niche experiments emerge and gain momentum owing to very strong landscape pressures on the electricity sector. In the other two pathways, a different momentum appears. The "reconfiguration" pathway predicts an emergence of transnational super-grids and the strong focus on EU influence and policies to ensure the security of supply in a geopolitically challenging landscape. Here, the role of prosumers would not be central owing to the dominance of large companies and centralized power plants, such as big off-shore windfarms or large solar PV plants. "Transformation" is a hybrid of the previous; here, production via both large power plants and small decentralized power plants co-exists, but the regime actors keep control and small-scale DERs are concentrated around niches rather than becoming widely mainstream (Verbong and Geels 2010). Ten years after Verbong and Geel's article, these pathways still seek form and direction and whether any of them will be the dominant one in moving forward is not known as evidence of all three is emerging. The authors considered "transformation" as the most likely scenario at the time; however, recent developments on transnational transmission networks suggest that also the development of super-grids is possible (Child et al. 2019; IRENA 2019).

SNM (R. Kemp and Rip 1998; Schot and Geels 2008) is a framework used in analyzing radical innovations. At the core of SNM are niche-level "protected places" where innovations are created and nurtured. Kemp and Rip (1998) identify several barriers for new technologies, such as sustainable transport technologies, to become mainstream: technological factors (new technology does not fit into the existing system), government policy and regulatory framework (conflicting messages and policy incentives), cultural and psychological factors (prefer the existing technology), demand factors (solutions are not proven, pricing), production factors (long cycle from development to mass production), infrastructure and maintenance (sunk investment), and undesirable societal and environmental effects of new technologies (waste problem of electric batteries). The new technology must be able to overcome several barriers; hence, "niches, protected spaces, that allow nurturing and experimentation with the co-evolution of technology, user practices, and regulatory structures," are needed, as Schot and Geels (Schot and Geels 2008, p 538) summarize (see also Figure 10).

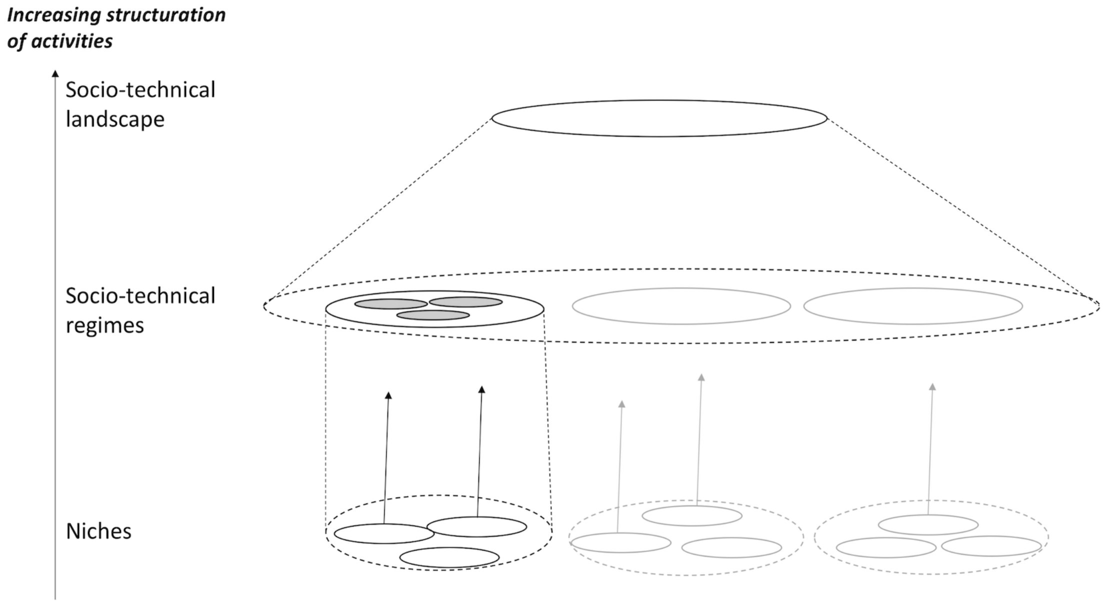

Figure 10. From niches to regimes, adapted from (Geels 2012).

Learning processes and social networks are key elements of the niches that develop both locally and globally, eventually shaping the technology trajectory. The notion of niche fits well into the MLP framework and is widely used in analyzing innovation policies (e.g., (Kivimaa and Kern 2016)).

Prosumers also fit nicely to the niche domain. Schot et al. (2016) propose a typology for users in transitions and identify five types of users i.e. user-producers, user-legitimators, user-intermediaries, user-citizens, and user-consumers that influence the transition in different levels and phases (see also Figure 11). The authors recognize user role in building niche markets and especially see that "user-producers" are critical for the success of local experiments. The role of grassroots innovations has been studied and considerable potential is seen in its positive effects on energy transition (Hossain 2016; Klein and Coffey 2016; Korjonen-Kuusipuro et al. 2017). User-centric and grassroots innovations as well as the co-design of novel solutions around energy and electricity could be influenced by consumers and prosumers if they are persuaded to participate. The authors also position these different types of users in the transition dynamics. For example, user-producers and user-legitimators are seen working through the niches, whereas user-intermediaries and user-consumers use the new technologies in their everyday life and practices and hence help niches to evolve into regimes (Schot et al. 2016). Furthermore, the authors propose that user-citizens actively participate in politics and hence increase the pressure toward regime shift.

As Schot et al. (2016) propose, users can be seen as intermediaries that have an important role as catalysts in transitions. Kivimaa et al. (Kivimaa et al. 2019) systematically reviewed literature related to intermediaries in transitions and identified their role in niche development, transition governance and in innovations. Different types of intermediaries operate on different levels of MLP. For example, systemic intermediaries operate on all levels, but niche intermediaries focus on certain niche developments. They also recognized the intermediation between consumers and prosumers (user intermediaries) in e.g. technology diffusion. (Kivimaa et al. 2019). Furthermore, Martiskainen and Kivimaa (2018) studied innovation intermediaries in different phases of zero carbon building projects in Brighton, UK and found intermediation and championing to be closely linked.

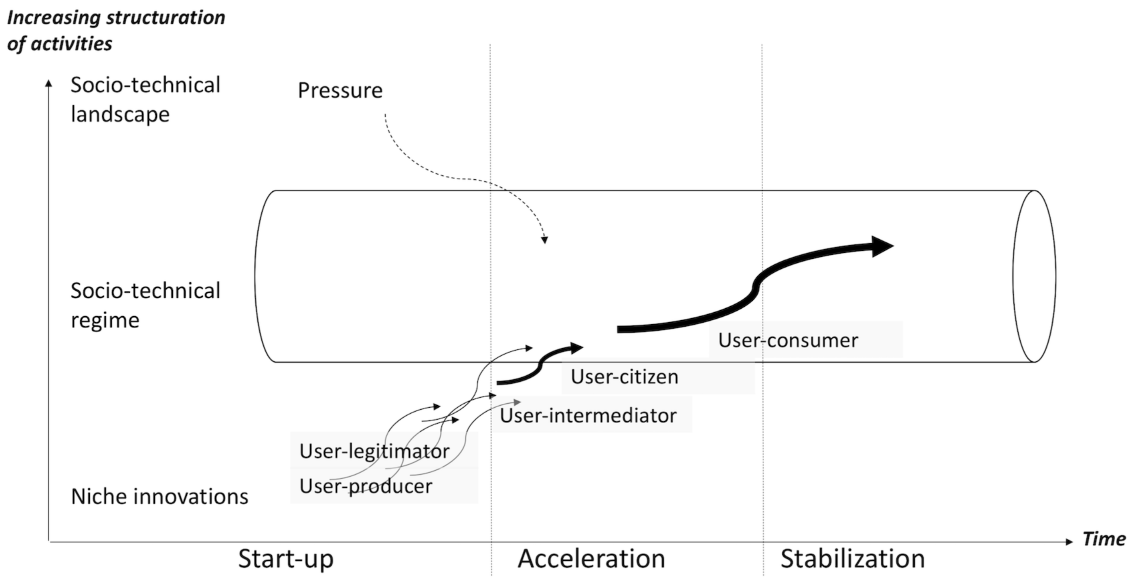

Figure 11. Users in transition, adapted from (Schot et al 2016)

2.3.3 Other theories related to sustainability transitions

TIS (e.g., (Bergek et al. 2008, 2015; Carlsson and Stankiewicz 1991) is another widely used framework focusing on understanding the emergence of new technologies. The TIS framework includes two core elements: structural components and functions.

The structural components of TIS are the actors, networks, and institutions that are involved in the change process. Actors can be individuals or any type of organizations or associations. Prosumer is a new actor in the energy sector; hence, the TIS framework could provide a suitable theoretical lens for observing the prosumers. The actors typically organize themselves into formal or informal networks: for example, standardization forums, public–private partnerships, and university–industry links that may take a role in orchestrating the technological change. Some networks, such as social communities or customer interest groups, may be in less orchestrating role than larger incumbent organizations. Institutions represent culture, norms, laws, and regulations (Bergek et al. 2008), and they play an important role as they need to be aligned so that technological change to take place.

The dynamics of emerging technology systems are explained as seven functions in TIS: knowledge development and diffusion, entrepreneurial experimentation, influence on the direction of search, market formation, legitimation, resource mobilization, and development of positive externalities (Bergek et al. 2008; Köhler et al. 2019).

The stability of the regime depends on how its different elements interact with each other. For example, incumbent companies and policy-makers often work together against changes by forming alliances. The incumbent firms have access to key resources and are important for national employment and economic growth; hence, they are influential to policy-making (Geels 2014). On the contrary, new actors, typically emerging form the niches, aim to destabilize the regime.

TM (Rene Kemp et al. 2007; Loorbach 2007, 2010) is a framework for analyzing and governing transitions in socio-technical systems. Rotmans et al.(2001, p. 16) define transition as: “a gradual, continuous process of change where the structural character of a society (or a complex sub-system of society) transforms”. Rotmans and Kemp (2003, p. 15) furthermore define transition management as a deliberate attempt to bring about structural change in a stepwise manner. TM is a policy-oriented framework suggesting that the change can be achieved in four steps. First, strategic activities need to take place in a “transition arena” that supports vision development and creation of transition pathways. These transition arenas bring actors from different backgrounds such as science, politics, industry, and civil society to work together in a co-operative manner. However, vested interests of strong actors induce resistance to change and forms barriers for productive outcomes. Second, tactical activities should be used to develop plans, policy agendas, and instruments. Third, operational activities should include demonstration projects and innovation experiments that accumulate knowledge through learning by doing.

Experiments have been found to advance social learning, challenge dominant values, and pave the wave for new actors. Individuals, such as residential energy prosumers, could get involved in niche experiments. Finally, reflexive activities in terms of project evaluation and monitoring must allow adjustments and help to create best practices (Köhler et al. 2019).

It has been argued that incumbent regime actors, public officials, and researchers dominate the transition arenas and that non-governmental organizations (NGOs), small and medium (SME) businesses, and citizen organizations have lesser roles (Kern and Smith 2008). In Finland, the Ministry of Employment and Economy initiated a smart grid working group in which large and small energy incumbents and academic researchers were invited to participate along with some representation of small-scale producers and citizen organizations. The working group produced a smart grid vision and subsequently proposed market roles, rules and incentives, technical pre-conditions, and sectoral co-operation (http://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/161147/TEM_39_2018.pdf?sequence=1&isAllowed=y). TM highlights the importance of governance and policy-making.

The theoretical frameworks described above are used in several streams of sustainability transition research. All frameworks are used in general research for understanding the transitions (Köhler et al. 2019). TM and SNM are commonly utilized in research related to governing the transitions (René Kemp et al. 2007; Köhler et al. 2019). Furthermore, SNM is a typical tool for innovations studies related to transitions (Schot et al. 2016; Schot and Geels 2008). However, the frameworks have also received criticism. For example, the socio-technical MLP (Geels 2002; R. Kemp and Rip 1998) has been criticized for its lack of agency, bias toward bottom-up change models, weaknesses related to the operationalization of regimes, problems with epistemology and explanatory styles, holes in methodology, treatment of the socio-technical landscape as a residual category, and flat ontologies (Geels 2011). Furthermore, while widely used in the context of transition studies, TIS has been criticized for not sufficiently considering its context during analysis as well as for being too weak from the politics and policy aspects (Markard et al. 2015).

2.4 Theoretical and empirical grounding of the research framework

The above-outlined introductions to energy prosumerism and to the key theories are now integrated into a research framework illustrated in Figure 12.

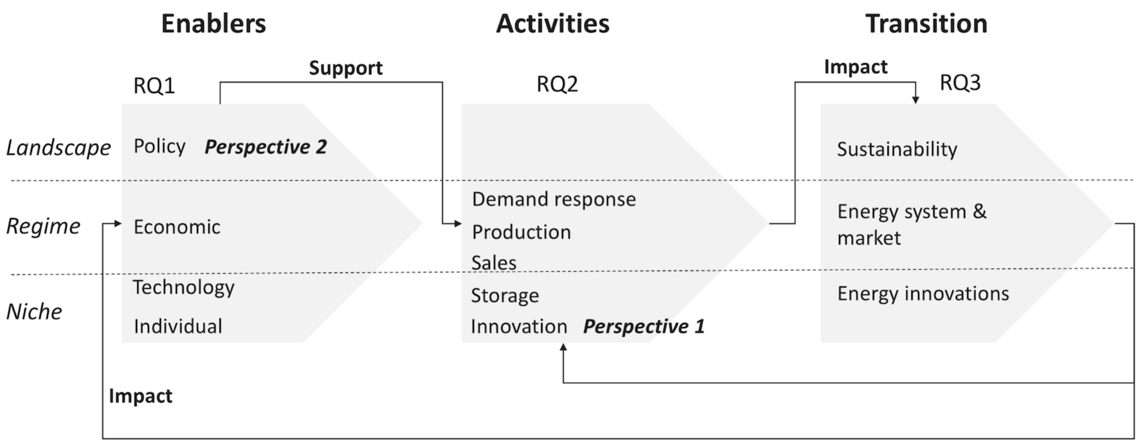

Figure 12. Analytical research framework.

One way to approach a single actor in transition is through understanding its role (Wittmayer et al. 2017). A "role" can be defined in multiple ways, one of which is based on the actor's activities and attitudes (Turner 1990; Wittmayer et al. 2017). First, the prosumer role as an actor in the energy transition is analyzed through **enablers, activities**, and (impact on) the energy **transition**. This dimension of the framework is based on a simplified version of the *intra-actor centric view* (Talmar et al. 2018). Key enablers, activities, and transition impacts identified based on literature are placed in the framework. Prosumerism can have multiple impacts on the energy transition and its related phenomena on all levels of the socio-technical framework. These impacts are observed in the context of sustainability, energy system and markets, and energy innovations.

Second, the research framework is vertically structured based on the *socio-technical MLP* (Geels 2002) into landscape, regime, and niche. Hard lines cannot be drawn between the socio-technical levels; hence, it is only possible to roughly position the enablers and activities in the socio-technical framework. For example, prosumer participation in innovation co-creation can quite typically be a niche-level activity. On the contrary, many activities are coordinated from the regime level. For instance, DR is organized by incumbent energy firms and is tightly linked to regime rules and processes. Energy sales can be considered either regime or niche activity based on their nature; P2P energy trading in experimental virtual communities clearly qualifies as a niche activity, whereas feeding energy to the power grid is in line with the existing regime systems. Energy production using solar PV can be seen as a niche or regime activity based on the installation size. Appended Articles I and II study the prosumer role from the transition perspective by covering multiple elements of the framework.

Third, two "perspectives" for the inquiry are chosen as *prosumers as innovators* and *policy as an enabler*. These perspectives dive deeper into two of the prosumer enablers and activities. The prosumers as innovators perspective addresses the innovation activity of the prosumers in appended Articles III and IV. The other activities are discussed at a more general level in the appended articles. The innovation perspective was selected as a special inquiry because it represents an activity that has been less researched than some of the other activities such as DR and energy production using solar PV (Masson et al. 2014; Ottesen et al. 2013; Pinto et al. 2017). Innovation activities of prosumers are also addressed in the STRN agenda (Köhler et al. 2019). Policy as an enabler is the second perspective of this dissertation. It focuses on policy as a prosumer enabler in appended Articles V and VI. Again, the other enablers such as technology, economic factors, and individual drivers are discussed at a more general level in the appended articles. Holistic studies particularly addressing prosumer-related policies are still limited and more research could help in the development of policy mixes to accelerate consumer-to-prosumer evolution (Inderberg et al. 2018; Ossenbrink 2017; Rogge and Reichardt 2016; Ruostetsaari et al. 2018).

Finally, RQs are integrated into the framework. RQ1 is predominantly connected to the enablers: A) How do different enablers contribute to consumers' evolution into prosumers? B) What is the role of policy in this regard? RQ2 focuses on the activities: A) What are the core prosumer activities in the energy system? B) How do prosumers contribute to the adoption and co-creation of energy innovations? RQ3 inquiries about the transition: What is the prosumers' role in energy transition and how do prosumers influence the transition?

Acknowledging that the analytical research framework can cover only limited aspects of the prosumer-related enablers, activities, and transition effects is important. Hence, concerning the enablers, only policy aspects are studied in more detail, thus leaving out detailed discussion on technology and economic and individual factors. Similarly, innovation activity is highlighted in terms of prosumer activities and others, such as DR, energy production, energy storage, and energy sales, are not addressed in detail in this research. Prosumer influence on transition is predominantly investigated in general in terms of sustainability, energy systems and markets, and energy innovations. Any other aspects of prosumer influence on the energy transition are not addressed in this study. Despite these limitations, this research will help in painting a more holistic picture of energy prosumers as actors in sustainability transition.

3 METHODOLOGY

3.1 Research approach, design, and process

The research problem at hand is complex and touches many levels of the society and techno-economic system. Multiple stakeholders need to work together to make energy transition possible, and this transition is very systemic and dynamic in nature. In such complex cases, essential knowledge may be easily missed when only one method or data source is used (Creswell and Plano Clark 2017). Hence, a multi-disciplinary approach and mixed methods are applied. Combining worldviews that fit to both qualitative and quantitative methods poses some challenges (Doyle et al. 2009). Creswell and Plano Clark (2017) suggest that for mixed method research, post-positivism, constructivism, transformative approach, or pragmatism could potentially be used. Of these, the pragmatism is widely accepted as the paradigm that suits well with mixed methods research (Doyle et al. 2009; Feilzer 2010; Tashakkori and Teddlie 2003). The pragmatic approach indeed fits well with the research at hand; it is a problem-centered and real-world practice-oriented method and has its focus on the results of the research. Furthermore, the pragmatic research can cover both deductive and inductive approaches depending on the research strategy used in different phases of the study. Ontologically, pragmatism allows the researcher to test hypotheses from multiple perspectives; epistemologically, it allows the researcher to be practical: that is, use "what works" (Creswell and Plano Clark 2017). Pragmatism also permits the researcher to focus on the study at hand rather than "dwell" on the questions related to the research philosophy (Tashakkori and Teddlie 2009).

Mixed methods research can be implemented in various ways (Creswell and Plano Clark 2017). Maxwell's (2012) integrative and system-based approach includes five key elements of the research, i.e., goals, RQs, conceptual framework, methods, and validity, that form an integrated system. Maxwell's approach fits well with the research at hand as it focuses on the systemic change of the energy system from the two perspectives that set the goals for the research. Integration of different levels of information (e.g., macro and micro) that is required is also well supported by Maxwell's approach.

Research design can be either explorative or conclusive. While there are signs of conclusive research in the quantitative research streams of the research at hand, the overall research design is explorative. Exploratory research is typically used in cases wherein clarification of the research problem and sharpening of the priorities are needed (Burns and Bush 2006). The research focuses on increasing the understanding of the novel phenomena of energy prosumers as part of the energy transition, which is an area that has multiple research gaps. Prosumers can be understood by exploring the different features related to them. Explorative research is typically used when the inquiry is about a new subject that has not been widely studied (Saunders et al. 2009). When I started the research in early 2016, prosumer research was still in its infancy; hence, the explorative research design was seen as a good fit with the RQs. Whereas conclusive research aims to provide final and conclusive evidence to the RQs, explorative research provides general and more tentative insights about the research problem, leaving ample room for future research to further address the topic (Brown 2006). In addition, compared with conclusive research, sample sizes in explorative research are typically smaller and more subjectively selected to maximize generalizability and the data analysis is generally more flexible.

3.2 Research data and analysis

Both primary and secondary data are used in the research. Main data collection was based on the following: 1) documentary reviews, 2) an explorative consumer survey in five European countries (N = 197) that was supported by 3) a large-scale citizen survey in Finland (N = 1349), and 4) a set of expert interviews in Finland (N = 14) and workshops. The results from these research streams are interpreted using quantitative and qualitative methods and the end result is six articles appended in this dissertation. The findings from this approach are integrated in the appended articles and synthesized in this introduction. Figure 13 summarizes the data usage in the appended articles in relation with the research design.

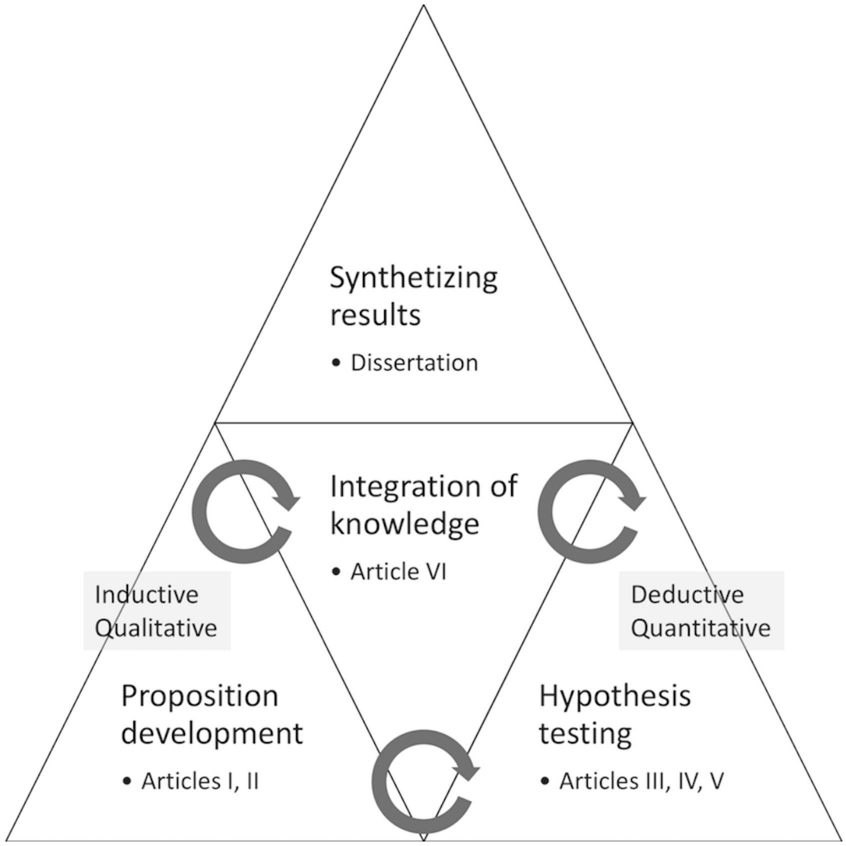

Figure 13. Research design perspective, data usage, and purpose in the appended articles.

Articles I and II focus on developing propositions based on the documentary reviews. The propositions are further developed into hypotheses and conceptual models that are tested using the consumer survey data in appended Articles III, IV, and V. The knowledge acquired was integrated in Article VI. Finally, this dissertation summary synthesizes the results.

Furthermore, Table 3 explains how different types of data were used in the appended articles and what methods were used.

Table 3. Data usage, research questions, key research methods, and articles.

Data source	Description	Research questions	Research approach	Data collection method	Analysis method	Articles
Consumer survey	N = 197, five European countries	1, 2	Deductive	Survey	Quantitative: PLS-SEM	Main data source: III, IV, V
Documentary data	Governmental and non-governmental documents and websites, industry reports, academic articles	1, 2, 3	Inductive	Documentary review	Qualitative: Documentary review Proposition development	Main data source: I, II, VI
Citizen survey*	N = 1349, Finland	1, 2	Deductive	Survey	Quantitative: Statistical analysis, policy analysis	Supportive: Dissertation summary
Expert interviews*	N = 14, energy experts in Finland	3	Inductive	Semi-structured interviews	Qualitative: Content analysis	Supportive: Article II, dissertation summary

*Supporting research stream

3.2.1 Documentary reviews

Documentary reviews based on secondary sources were utilized in the research design phase, in the integration of the findings, for introduction writing, and as the main data sources in appended Articles I, II, and VI. The documentary reviews were explorative in nature and used multiple data sources. This type of multivocal reviews are suitable when the researcher wants to form an understanding of a new topic that has not been much researched (Ogawa and Malen 1991).

In this research, mainly secondary documentary data was used. Secondary data typically include documentary, multiple source, and survey data (Saunders et al. 2009). The main data sources were government websites, European industry associations, and reports for EU institutions concerning prosumers or related topics. Another major source of literature was academic articles. Theoretical research frameworks, key concepts, and literature reviews formed the basis of the research framework development. Documentary data was used to explore and build an understanding of prosumer enablers and activities as well as their role in the energy system and transition.

A systematic literature review was conducted in order to understand the width and breadth of the research on energy prosumers. In the review focusing on energy prosumers, SCOPUS and Web of Science databases were searched using "energy" and "prosumer" as the search parameters. The search results were further narrowed down by using selection criteria that allowed omitting non-energy prosumer related literatures and focused on the articles that were a) highly cited, b) were published in highly cited journals, and c) were novel. The results of the literature review were used in research design and as source of references in writing the articles.

Selection of the documents related to socio-technical systems, ecosystems, innovation, policies and energy technologies and business models were done pragmatically during the research and relying on the research questions. Table 4 summarizes the documentary data usage. More specific data sources used in the documentary reviews are provided as references in the appended articles.

Articles I and II rely on documentary data for proposition development, and Articles III, IV, and V rely on it for concept development and hypothesis building. Documentary data were also used in Article VI to perform a high-level policy mapping exercise of command-and-control, economic, and soft instruments with prosumer activities. In the case of policies, government documents are commonly treated as primary data.

Table 4. Documentary review focus areas in the research.

Document focus	Analytical focus	Examples of content	Theoretical frameworks	Examples of references
Socio-technical systems	Transition	Socio-technical landscape, regime, and niche Path-dependencies, lock-in Stability vs. change	Socio-technical MLP SNM TIS TM	(Geels and Schot 2007; Loorbach 2007; Markard et al. 2015; Schot and Geels 2008)
Ecosystems	Transition	Innovation ecosystem, business ecosystem, digital business ecosystem Actors and networks	Triple, quadruple, quintuple helix model Open innovation	(Adner 2006; Carayannis et al. 2012; Chesbrough and Appleyard 2007; Nachira 2006; Oh et al. 2016)
Innovation studies	Activities, enablers	Open innovation Co-creation User-centric innovation Grassroots innovation Sustainable user innovation Lead-user innovation Living labs, smart cities	Open innovation User-centric innovation Co-creation Diffusion of innovations TAM	(Chesbrough and Appleyard 2007; Davis 1985; Prahalad and Ramaswamy 2004; von Hippel 2005)
Policy mixes	Enablers	Policy instruments in transitions Prosumer policies	Policy cycle Policy mix	(Howlett and Ramesh 1995; Rogge and Reichardt 2016; Vedung 1998)
Prosumers	Enablers, Activities, Transition	Definitions Barriers Drivers Prosumer base in Europe	Intrinsic & extrinsic motivations Bounded rationality	(European Commission 2009, 2017; IEA-RETD 2014; Kampman et al. 2016)
Energy activities and technologies	Enablers, activities	Production Storage Sales EVs Blockchain Smart grid Smart meters	Socio-technical MLP SNM TIS TM	(European Commission 2017; Figenbaum 2017; Honkapuro et al. 2017; IEA 2017; International Energy Agency (IEA) 2016; Mengelkamp et al. 2018; Miller and Senadeera 2017; Schamela 2018)

3.2.2 Consumer survey

Survey as a research strategy allows for the collection of potentially large amounts of quantitative data (Saunders et al. 2009). Survey data was used as the main data source of appended Articles III, IV, and V. The main objective of the survey was to better understand consumer decision-making concerning RET adoption, policy influence, and interest in innovation activities in a broad sense. A quantitative approach was selected to obtain a better representation of the population.

The survey was designed by a research group including researchers from the Tampere University and CERN. The questionnaire included 79 questions inquiring about different aspects of RET adoption and use. The questionnaire design was based on literature review on energy prosumers and theoretical concepts related to e.g. diffusion of innovations, attitudes toward adopting RET, co-creation and user-centric innovations, and policy instruments related to RET. The questions were designed as statements focusing on the decision-making criteria and motivations for RES investment, environmental attitudes, interests on co-creation activities, and preferences for incentives and other support for RES adoption. A seven-point Likert scale was used to rate the responses. In addition, various demographic data were collected, including housing type, income level, education, and age. Subsets of this broad questionnaire were used in the appended articles.

The data were initially collected in four European countries in the summer of 2016: France, Germany, Italy, and Switzerland. Data were collected in Finland a few months later at end of 2016 and early 2017. Countries selected for the consumer survey feature typical yet diverse cases (Gerring 2013). They are typical in being high-income, coordinated market economies with parliamentary political systems. They are all integrated in the European energy market and all except Finland are situated in the heart of the central European markets. Four out of the five countries, namely Finland, France, Germany and Italy, share common commitment to the EU's 40% target for GHG emission cuts by 2030, while they also have common targets for reaching near zero emission energy systems by 2050. Switzerland, while not a member state of EU, has adopted similar targets for the Swiss energy system and is aiming to achieve zero net carbon emission by 2050 ("Federal Council aims for a climate-neutral Switzerland by 2050" 2019). The selected countries also have clear differences. Geography of the countries vary remarkably, which explains partly their distinctive energy mixes. Italy and Germany are still heavily relying on coal. Finland, France and Switzerland have nuclear plants. Finland and Switzerland also have hydro power. Germany and Italy especially are investing in solar energy.

The countries are also different from the socio-technical point of view e.g. in their energy policies, regulation, and energy production as well as public attitudes toward renewable energy (Valta 2017). Germany supports solar generation and batteries but has been slow to introduce smart metering. Italy is Europe's second biggest market of solar PV but aggregation and demand response are not as developed. Finland has good market conditions and advanced smart metering infrastructure but does not incentivize solar energy. France has established regulation for demand response and incentives for microgeneration and EVs. Switzerland has a dispersed policy landscape as cantons' role is emphasized. It is a frontrunner in microgeneration and demand response but lags behind in smart metering.(FinSolar 2019; Rosen and Madlener 2016; Valles et al. 2016; Valta 2017; S. Zhou and Brown 2017).

In order to improve the quality of the survey, native speakers translated the questionnaire from English into French, German, Italian, and Finnish. The questionnaire was first tested with the translators to prevent any statements that might cause confusion or be easily misunderstood. Slight modifications were made after this piloting round.

The data collection took place in face-to-face setting in Tours, Toulouse, and Saint-Genis Pouilly in France; Freiburg, Aachen, and Munich in Germany; Napoli, Firenze, and Moncalvo in Italy; Geneva and Spietz in Switzerland; and Tampere in Finland. In addition, the questionnaire was made available online: the respondents who were unable to participate at the time were given an opportunity to answer the questions later online. Questionnaires are efficient when respondents have similar understanding of questions (Saunders et al. 2009); the researchers clarified some statements that raised questions as needed.

The data sample of this particular survey is 197 respondents. The intention was to collect a sample that would characterize the distinctions between the surveyed countries as well as detect key differences between prosumers (RES owners) and consumers. Owing to the explorative nature of the study as well as the limited availability of resources, the sample size was restricted to approximately 30 per country. Non-probability purposive sampling was used in order to ensure both prosumers and non-prosumers in the sample. In total, 75 of the respondents were prosumers and 122 were consumers. Respondents that indicated having "Solar panels," "Wind," "Geothermal," and "EV" at their disposal were considered as prosumers and the others were considered normal consumers.

Data collection predominantly took place in public spaces, such as airports, railway stations, and city parks. In order to fulfil the target of reaching a sufficient number of prosumers, i.e., RET owners, the questionnaire was delivered door-to-door in residential areas that had solar panel installations on rooftops. These neighborhoods were found using Google Maps' satellite images. Selecting residential areas may have created bias as inhabitants' demographic features, such as income and educational background, may be relatively homogenous in neighborhoods. Young adults (25-40) were overrepresented and middle-aged adults (41-55) were underrepresented in the samples from Germany and Switzerland. In French and Italian samples the age distribution was closer to actual situation but older adults (55-) were slightly over-represented (CIA 2016). Demographic information (average) of the survey respondents is presented in the Table 5.

Table 5. Average demographic summary of the survey respondents

Characteristics	Description	%
Age group	18-24	18.4
	25-40	40.3
	41-55	15.3
	>55	26.0
Education	Primary school	4.7
	Secondary school	28.1
	Bachelor's degree	19.3
	Master's degree	47.9
Income	<3000 €	38.5
	3000-6000 €	37.0
	>6000 €	24.5

The response rate of the survey was 30,0%. Quantitative methods were applied to analyze the data. The methods included statistical analysis, principal component analysis (PCA), and partial least squares structural equation modeling (PLS-SEM). The data analysis method is discussed in more detail in the respective articles. PLS-SEM was used in Articles IV and V as it fits well to research exhibiting small sample size, explorative research, and the desire to model the causal effects of certain parameters (Hair et al. 2014; Sarstedt et al. 2017). The analysis results are discussed in the article summaries in the next chapter. It should be noted, that the Article III uses data set from France, Germany, Italy and Switzerland as the results from the Finnish respondents were not ready, due to later data collection than in the central European states, at the time of writing the article.

3.2.3 Supporting data sources

Supporting data sources of the research were a citizen survey (N = 1349) and expert interviews (N = 14). These data sources were used for designing the conceptual models and frameworks for the appended articles and for synthetizing the results of the inquiries. The data was collected in the EL-TRAN and ProCem projects, respectively.

Citizen survey (N = 1349)

A national citizen survey was administered to collect information about consumer attitudes toward RET adoption. This was part of a large survey developed by the strategic research project EL-TRAN in Finland funded by the Academy of Finland. The survey was implemented as mail and internet questionnaire for randomly selected 18-75-year-old in the mainland Finland. The response rate of the survey was 33,6%. I designed a set of questions that formed a subset of the survey that inquired citizens' attitudes toward energy politics, production, sales, and storage.

Data analysis was performed using quantitative methods and the SPSS software (https://www.ibm.com/analytics/spss-statistics-software). The results concerning the prosumer attitudes toward own energy production have been published as policy analysis papers by EL-TRAN (Kojo et al. 2018; Kotilainen et al. 2018; Ruostetsaari et al. 2018).

The results accumulated understanding of the consumer attitudes toward adopting RET and changing their energy behavior. However, the data obtained from the consumer survey was not broad enough to address the research questions and hence the consumer survey data was used in most of the articles. The data nevertheless contributed to the overall understanding of consumer-to-prosumer evolution with regard to both macro- and micro-level drivers and enablers and the findings were utilized in the research design and interpretation of the data in appended Articles III, IV, and V as well as in the integration of the research results.

Expert interviews (N = 14)

Expert interviews complemented the research. The interviewees were Finnish energy industry experts participating in the ProCem project as company representatives. They represented both incumbent actors, such as TSO, DSO, energy retailers and energy consultants and large energy technology providers, as well as new actors, such as ICT companies and energy communities. In total, 14 interviews were conducted in December 2016, in which data of the factors affecting the energy prosumer role in the Finnish energy system were collected and analyzed. The interviews were semi-structured, meaning that an interview guide was followed and both open-ended and close-ended questions were asked. An advantage of semi-structured interviews is that the interviewer can be well-prepared but there is still room for exploring different trajectories that arise during the interview (Saunders et al. 2009). The technique is hence useful when the topic is new and complex. The interview results are not directly used in the appended articles, but the information was used to form an integrated understanding of enablers, activities, and especially the impact on the energy transition in Article II, in the design of the research framework, and in writing the dissertation summary.

Interviews, as the other qualitative research methods, are prone to researcher bias (Barriball and While 1994). To reduce the bias, the interview plan was reviewed by peer researchers participating in the ProCem project. Data collection was conducted via interviews that lasted about two hours each; one interview was conducted over the phone owing to schedule conflicts. The interviews were not recorded to allow more opportunities for "off the record" type of commentary on the topic. The interviewer took notes during the meetings, and after the meetings, the notes were shared with the participants, who had a chance to make corrections to the notes. Some minor details were corrected based on the feedback.

A large part of the interviews focused on discussing and collecting factors that might affect prosumerism in Finland during the next 10 years. In Article I, the PESTEL elements were suggested as landscape-level influencing factors to the prosumer-centric energy transition. In the interviews, each of the PESTEL elements: political, economic, social, technological, environmental, and legislative, were covered. The interviewees were asked to rate both the impact and uncertainty of each factor they proposed on a scale of 1–10, wherein 1 represented non-significant impact or very low uncertainty.

During the analysis phase, the collected material concerning these factors was grouped into 26 group factors including, for example, "Economic development of solar PV price levels." These were then positioned in an uncertainty matrix (Maack 2001). Based on the results, different scenarios for the prosumer role in the Finnish energy system were developed. The results of the analysis were presented to the participants in a project meeting. The results were used for research design and interpreting the data concerning particularly the appended Articles II and VI.

3.2.4 Research projects

In practice, the research was conducted during 2016–2019. The appended articles were written as part of two main research programs. First, the *Social Energy Prosumer centric energy ecosystem* (ProCem), (http://www.senecc.fi/projects/procem-2) project (2016–2018) focused on researching and piloting technical solutions and examined the role of prosumers in the development of the energy system. The project studied the creation of new ecosystems based on prosumer activities and generated understanding of the business models based on digitalization and the sharing economy in the electricity sector. The implementation of the project required a multidisciplinary approach that combined decentralized resources and technical and financial management of the electrical system, new functionalities enabled by ICT, the optimal use of resources from the perspective of different actors, and new business models and ecosystems. The project was conducted by research groups from four different research laboratories in Electrical Power Engineering, Information Technology, Automation and Hydraulics, and Industrial Engineering and Management in collaboration with the participating business partners. My role in this project was to study prosumer role in the energy system. I worked on prosumer definitions and use cases of prosumers as participants in digitalized platforms. I also studied the policies and the energy transition from the Finnish perspective. Second, *Transition to a resource efficient and climate neutral electricity system* (EL-TRAN, www.el-tran.fi) project (2016–2021) studies what a resource-efficient electricity system means, how it is implemented, what policy issues we face, and how we ultimately solve the issues. The consortium is building a roadmap for a resource-efficient electricity system in Finland. The project publishes policy analysis and conducts simulations of the energy system based on low-carbon variable energy sources. The consortium is multi-disciplinary, combining several research institutes and researchers from the field of politics, engineering, law, future studies, and building and construction studies. My role in this project was to conduct research and write policy analysis related to prosumers, electric mobility and sustainability transition.

The six appended articles represent a sub-set of publications that I wrote during these projects. In addition to the research projects, I made research visits to the University of Lausanne and the Energy Policy Research Group (EPRG) at the University of Cambridge during the dissertation process.

Before moving into discussing the appended articles and results, Figure 14 illustrates the overall research flow 2016-2020.

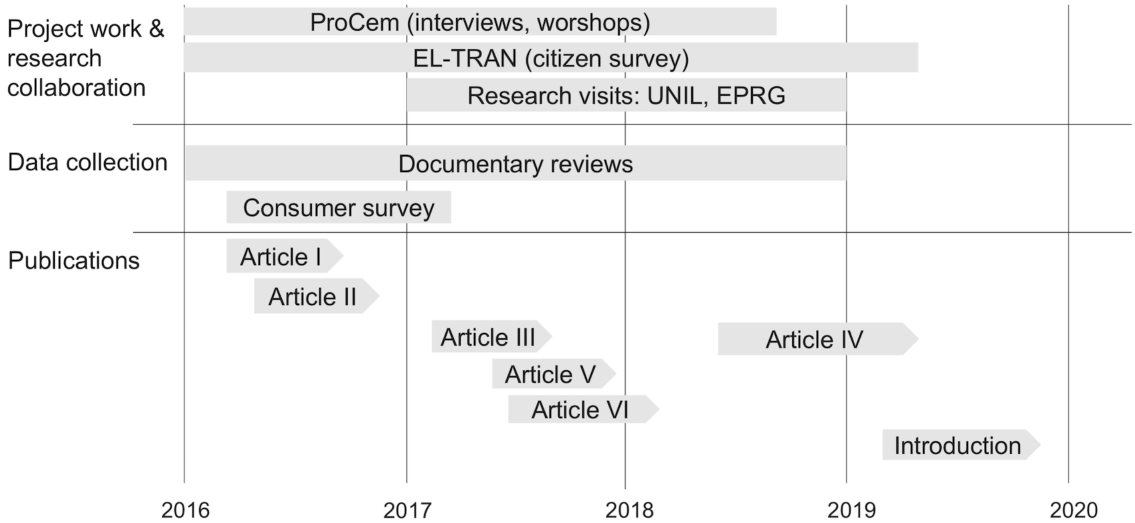

Figure 14. Temporal overview of the research flow

4 FINDINGS FROM THE ARTICLES

The appended publications are summarized in this chapter: Article I and Article II explore the prosumer role in the socio-technical system. Article I develops a set of propositions that are further studied in Articles III–VI. Article II positions the prosumers in the future energy ecosystem through the development of a propositional prosumer-centric energy ecosystem framework and discusses digitalization as an enabler for energy innovations.

Articles III and IV focus on the perspective one: *prosumers as innovators*. Individual motivations, personal characteristics and needs, and environmental attitudes are evaluated as potential drivers for prosumer interests toward innovation and collaboration.

Articles V and VI focus on perspective two: *policy as an enabler*. The articles analyze policy as an enabler for adopting renewable energy technologies and in the context of a proposed sustainable EV–prosumer (SEP) framework. Article VI also provides a mapping of typical policies concerning different prosumer activities.

Each of the summaries are structured so that they briefly summarize the article, present the key findings, and highlight the contributions.

4.1 Article I: Prosumers in energy transition

Based on literature review, this paper positions the energy prosumer as part of the smart grid innovation ecosystem and in the socio-technical MLP (Geels and Schot 2007) context. Smart grid is introduced as an enabler of an energy-efficient and environmentally friendly energy market and critical infrastructure of society (Järventausta et al. 2011). The role of ICT is highlighted: smart grids are highly digitalized power grids that allow bi-direction flow of information. Based on ICT, smart grid supports consumer and prosumer integration into the energy system (Järventausta 2015). It is stated in the article that "In order for the Smart Grid to succeed and fulfill its efficiency and sustainability goals, it needs a large and dynamic prosumer base." It is, however, noted that such a prosumer base does not widely exist in most markets, thus currently positioning smart grids at the early market phase (Rogers 1995).

The paper proceeds to discuss the energy transition from the socio-technical MLP and introduces the key concepts of the socio-technical landscape, regime, and niche based on studies by Geels and Schot (2007), Geels (2011), and Kemp and Rip (1998). As part of the energy transition, new actors emerge. Prosumer is positioned as a new actor in the energy system at the niche level of the socio-technical MLP framework. Some of the key drivers for prosumerism are identified: economic drivers, behavioral drivers, technology drivers, national condition, and ethical drivers (based on IEA-REDT, 2014). Similarly, some of the key barriers are listed: privacy and security concerns, need for behavioral change, lack of business models, complexities of new technologies, and risky cost/benefit structures (based on Verbong, 2013).

Diffusion of innovations is another theoretical concept of the article (Rogers 1995). Different adopter categories starting with innovators and early adopters and moving through early majority, late majority, and laggards are introduced. As smart grids are still in the early market phase from the consumer engagement perspective, the prosumers are suggested to be mainly innovators and early adopters that can contribute to the overall value creation in the ecosystem by acting as testers of new functionalities, co-creating new solutions, acting as opinion leaders, and promoting innovations to their peers.

The findings of the literature review are presented in the form of propositions that are developed in this paper to explore the prosumer role in the smart grid environment, especially from the viewpoint of how prosumers could accelerate the adoption of smart grid features. For example, Finland was one of the front-runners in smart metering deployment in Europe, but the customer adoption of innovations based on advanced metering infrastructure is still very low. See Table 6 for the summary of the propositions. Each proposition is discussed in the paper in more detail.

One of the conclusions of the paper is that most of the current[2] prosumers are innovators or early market adopters, as defined by Rogers (1995), that are eager to test new functionalities, validate business models, play with the technologies, and act as opinion leaders in their social circles as well as co-create novel innovations. It is also proposed that the actual success of smart grids depends on how well prosumers get engaged. The paper concludes as follows: "Macro-level actions already taking

[2] At the time of writing, early 2016.

place, bottom up activation of early market prosumers is the next step in Smart Grid technology diffusion and industry transformation towards flexible energy systems."

Table 6. Summary of the propositions (Kotilainen, Makinen, et al. 2016)[3]

Number	Proposition
P1	Top-down macro-level actions to push the Smart Grid ecosystem are necessary enablers for the technology development, removing barriers and lowering the adoption threshold but they are not sufficient alone to guarantee the Smart Grid success among end users.
P2	Smart Grid prosumption adoption is in the early market phase globally and is currently adopted by early market prosumers.
P3	Early market prosumer role is to test functionality and relative advantage of Smart Grid innovations.
P4	Early market Prosumers role is to test financial benefits of innovations and they are interested in Smart Grid innovations that exhibit same or higher levels of CAPEX than existing energy solutions while OPEX may remain risky.
P5	The role of early market prosumers is to validate Smart Grid innovations that exhibit lower levels of OPEX and same or lower CAPEX than existing energy solutions so that late market prosumers can adopt these innovations
P6	The role of early market prosumers is to tinker with technology and be opinion leaders as they are tolerant to technical difficulties and complexities of early versions of innovations
P7	The early market prosumers role as co-creators with technology developers and pioneering companies can lead to improvements needed in the whole product to satisfy the mass market needs and initiate the ecosystem growth

CAPEX = capital expenditure, OPEX = operational expenditure

The propositions were further developed into hypothesis that were explored in the consecutive research papers, especially in the appended Articles III-V.

The core contributions of the paper are discussed next. First, the Article I positions the prosumer as an actor in the socio-technical MLP and in the smart grid system. Prosumer is seen as an active participant in the niche innovation ecosystem around smart grids. Second, it suggests a set of propositions for the energy prosumer role in the smart grid environment, which contribute to the understanding of the prosumer role in the ecosystem. Third, it sets the direction for the next steps in the dissertation research to focus on both the macro-level influence and micro-level

[3] Unless otherwise indicated, the text is verbatim from Article I.

bottom-up prosumer activities. Overall, the article contributes to the sustainability transition research in terms of its propositional positioning of the energy prosumer as a (central) actor in the energy system's sustainability transition.

4.2 Article II: Prosumers in a digital energy ecosystem

Appended Article II proposes that the energy system is moving toward a decentralized, open, digitalized, and flexible *ecosystem* of actors and platforms and discusses the prosumer role in such a *digital* ecosystem. The article explores the digital energy ecosystem and how prosumers fit in as value-creating actors.

The theoretical background for the study is laid out by introducing the socio-technical MLP (Geels and Schot 2007) as the framework for the context of the inquiry, after which the changing industry dynamics of the energy regime are discussed. Here, the concepts of industry forces (Porter 2008), natural and perceived inertia (Hacklin et al. 2010; Prahalad and Bettis 1986; Spender 1989), and dominant logic help in understanding the challenges the energy regime faces as part of the transition.

The theory in the context of the paper is built on three assumptions: 1) Prosumer is an actor that has the roles of both producer and consumer; 2) platform providers' roles are currently in flux, with conflicting interests causing tension; 3) the core element is the product or service whereas the business model as the source of dynamics, often systemic, is not well-defined. These changing dynamics in the energy industry are potentially opening opportunities for actors like prosumers; however, nothing is certain as the incumbent firms continue to be powerful, well-connected, and with access to key resources. Regime resistance to renewal is a barrier for prosumerism as well as to the transition in general. One of the challenges is that the clock speeds of the incumbent energy actors and new entrants from ICT industry are quite different. This poses challenges for collaboration. However, recent examples of software-intensive start-ups such as Airbnb and Uber have proved that the roles of customers and suppliers can dynamically change and fast growth can be initiated with an innovative approach. In this article, we ask "Can ecosystem type of working methods be applied to energy sector so that prosumers as a group could produce energy with a (large) scale and fast speed?"

The theory section also presents different notions on ecosystems: innovation ecosystem, business ecosystem, and digital business ecosystem (Adner 2006; Chang and West 2006; Nachira et al. 2007; Oh et al. 2016). Here, a digital innovation ecosystem is selected as the framework for prosumer positioning. The theory review outlines the current thinking on the innovation models, such as the triple, quadruple helix, and quintuple helix innovation models (Carayannis et al. 2012; Leydesdorff 2012). User-centric innovation models have been introduced with the notions of open innovation, co-creation, and user-led innovations (Chesbrough 2003; Prahalad and Ramaswamy 2004; von Hippel 2005).

As a result of the literature review, a propositional framework for the prosumer-centric digital energy ecosystem is introduced. The framework has two main building blocks: actors and layers. Actors comprise the incumbent energy system actors, new entrants from other industries, and digital actors, i.e., platforms, software, and hardware. The layers in the framework are based on the simplified adaptation of the Internet of Things (IoT) layers (Kavis 2016). The proposed framework is depicted in Figure 15.

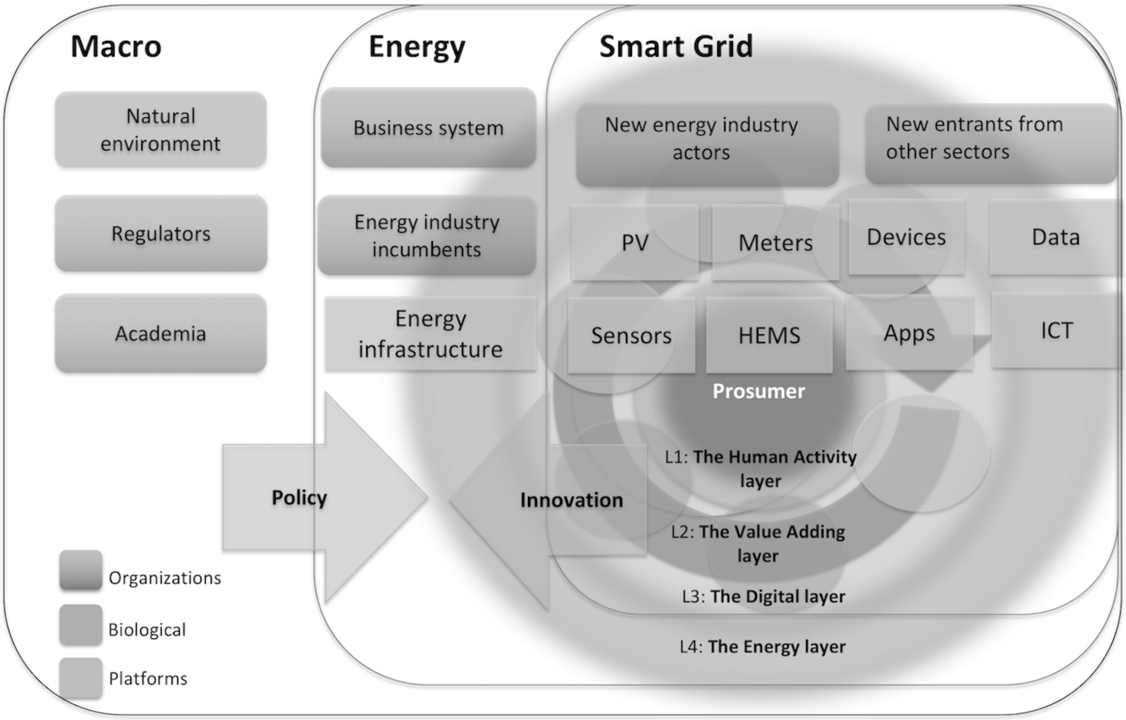

Figure 15. Prosumer-centric digital energy ecosystem framework (Kotilainen, Sommarberg, et al. 2016).

Through touch points to different levels of activities in the ecosystem, prosumers are suggested to contribute to ecosystem value creation in the form of innovative new services, new functionalities, and new processes. In addition, some of the key obstacles that may slow down end-user participation in the digital energy ecosystem activities are discussed.

The paper contributes to the understanding of end-users as part of the changing energy system and hence contributes to the sustainability transition studies. The paper also contributes by considering the view of an actor in the changing energy system context. Furthermore, the value-adding opportunities arising from more active citizen participation are proposed. It also contributes by proposing potential areas of prosumer innovation co-creation in the digitalized energy system.

4.3 Article III: Prosumer interests toward co-creation

Article III explores whether consumers and prosumers are interested in co-creation, what type of co-creation activities they prefer, and what kind of rewards they would choose in return for their contributions. The research data are based on the consumer survey conducted in Europe but excludes the data collected from Finland (N = 163) due to later collection of survey data in Finland.

Theoretical background of the research is first introduced, including key theories related to energy transition, NPD process, open innovation, and co-creation as well as motivations and rewards. The research has two main objectives: to inquire about consumer and prosumer interests toward co-creation and gain better understanding of the rewards the participants prefer.

First, the interest toward co-creation was evaluated based on a survey question: *How interested would you be in collaborating to develop Renewable Energy Products and Services?* The question included sub-questions related to interests toward providing ideas for new product functionalities and services, co-development of products and services, testing products and services before they become commercially available, giving feedback on renewable energy related products, giving feedback on renewable energy related services, and validating new business models. The scale to answer the questions was a seven-point Likert scale.

During the analysis phase, the co-creation actions were mapped into the NPD process stages (Cooper 2014): Pre-NPD, R&D, demonstration, and commercialization; the results were analyzed based on this framework. The results for this first inquiry show that there is overall a high level of interest toward co-creation and that interest was more skewed toward the later stages of the NPD process, namely demonstration and commercialization. In other words, the respondents seemed to be more interest in testing new products and services, validating business models, and giving feedback rather than in providing new ideas and participating in co-development. The co-development interests received the least positive responses. This result is logical because co-development requires a high level of technical know-how and therefore the potential pool of participants is naturally limited (Füller 2010).

Second, this article explored what kind of rewards are of most interest to respondents. The reward options included sense of belonging to a community, being part of creating better environmentally sustainable products and services, enjoying the process and having fun, learning new things, monetary compensation, gifts and rewards, challenges and competitions, career opportunities, exclusive information, and recognition from others. Interest toward these options was also measured using the seven-point Likert scale. During the analysis phase, the reward options were divided into intrinsic or extrinsic types (Ryan and Deci 2000). The results for the second inquiry showed more interest toward the intrinsic rewards, such as learning new things and enjoying the process and having fun than toward the extrinsic rewards, such as monetary compensation and career opportunities.

The paper mainly contributes to user-centric innovations, SEI, and grassroots research, which is one of the research areas in the sustainability transitions agenda (Köhler et al. 2019). The paper contributes to the theory in terms of linking co-creation activities with NPD process stages and mapping different rewards with motivation types. The empirical contribution of the paper provides further understanding of the consumers and prosumers as innovators and their preferences on the type of co-creation. Another empirical contribution is the analysis on the rewards preferred in exchange for co-creation.

4.4 Article IV: Micro-foundations of co-creation interests

Article IV builds on the previous research (Article III) with the goal of gaining deeper understanding of the potential micro-foundations behind the innovation and co-creation. Whereas Article III inquired about the *interest level* of consumers and prosumers toward collaboration, this article focuses on studying *why* consumers and prosumers are interested and how they differ in this respect. The research is based on the same consumer survey as that used in Article III but includes the data collected in Finland in addition to that in Italy, Germany, France, and Switzerland (N = 197).

Literature review and theoretical background focus on energy innovation, SEI, and other key concepts of innovation such as open innovation (Chesbrough 2003; Lee et al. 2012; Prahalad and Ramaswamy 2004), user-centric innovation (von Hippel 2005), and co-creation. The review then focuses on building hypotheses for potential micro-foundations of consumers' co-creation interests and building a conceptual model to explore the hypotheses. The conceptual model is presented in Figure 16.

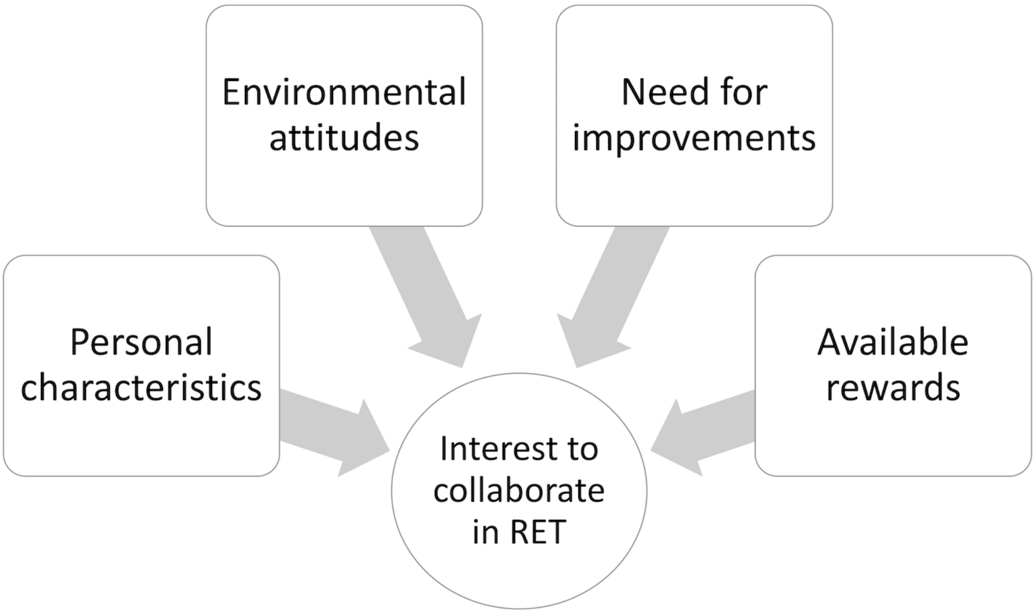

Figure 16. Conceptual model to address the micro-foundations of end-user interest in RET collaboration (Kotilainen, Saari, et al. 2019).

The empirical survey then probes into the drivers behind the collaboration interests that are explored in the previous article. Both first-order and second-order constructs are used in the conceptual model. Personal characteristics are divided into early and late adopter characteristics based on the diffusion of innovations theory (Rogers 1995). The need for improvements is either based on positive or negative feedback or on feedback related to required improvements. Available rewards are grouped as intrinsic or extrinsic. Environmental attitude is a first-order construct.

The conceptual model is analyzed using PLS-SEM as the method. This method is well-suited for explorative research and smaller sample sizes owing to its bootstrapping ability (Hair et al. 2014). The results indicate that most hypotheses related to personal characteristics and rewards are supported. The model does not find basis for environmental attitudes as a micro-foundation of collaboration interests. Moreover, positive or negative feedback or late adopter characteristics are not found to be indicators to collaboration interest.

Empirical findings of the research highlight the importance of early adopter characteristics and intrinsic rewards as micro-foundations of collaboration interests. Environmental attitudes do not play a similar role based on this research. Early adopter characteristics and rewards based on intrinsic motivations showed highest correlation with the interest to collaborate. Environmental attitudes only have weak connection with interest to collaborate. Giving feedback on improvements is correlated with the interest to collaborate, but other types of feedback do not correlate with these interests.

The results are further mapped as Importance – Performance Matrix (IPMA) which gives more insight into the differences between prosumers and consumers. The IPMA presents graphically the total effects on the x-axis with the latent variable scores on the y-axis (Ringle and Sarstedt 2016). Indeed, prosumers and consumers seem differ in some aspects: prosumers for instance exhibit stronger early adopter characteristics and are more in need of intrinsic rewards. Based on the results, the performance of these attributes is not however as high as it could be, meaning that there is potential for companies to develop their offering and approach targeted at the energy prosumers in these areas.

The study is implemented in five European countries that exhibit both similarities and differences. All countries are high-income and high-welfare societies with very similar targets to reduce CO_2 emissions. However, there are clear cultural and geographical differences that may affect how consumers and prosumers innovate. For examples, Finland has less residential solar than the other survey countries but the ratio of consumers versus prosumers in Finnish sample was rather similar to that of the other country samples. Hence, it could be assumed that the prosumers participating in the Finnish study could be considered as almost entirely innovators and early adopters. The study did not analyze the results per country, mainly due to the limited sample size, but for future research, more comparative approach in the country level could be beneficial.

The article contributes to the research on user-centric innovations, SEI, and grassroots innovations as well as to the understanding of the behavioral aspects of energy prosumerism. The contributions can be linked to both theory and practice; the theoretical contribution of this paper that includes a conceptual framework of the factors affecting interest to collaborate is introduced. The practical contribution suggests that different approaches to address consumers and prosumers as potential collaboration partners could be beneficial owing to their different preferences.

4.5 Article V: Policy influence on prosumers

The role of consumers is acknowledged to be significant in mitigating climate change. While many technology enablers for energy prosumerism are already available, can and will the prosumer base grow and become a meaningful entity in the future energy system? We explore this question through the adoption of RETs as a step toward cleaner energy. This particular article assesses how policies might affect consumers' willingness to adopt RETs and related products and services. Prosumers are used as a control group in this study because they have already made the decision to adopt RETs.

Policy support is widely agreed to be a critical necessity and an accelerator of sustainability transformations (Rogge and Reichardt 2016). The goal of this paper is to evaluate the effects of economic and non-economic policies on consumers' attitudes toward adopting RET solutions. The non-economic policies refer to policies such as regulation and information and education and also to policies that can enhance the use or accessibility of the products and services, for example through encouraging the development of turnkey solutions. In this paper, consumers' and prosumers' attitudes toward using RETs are explored by means of a consumer survey. The article studies how policy influences the attitudes toward accepting RETs and hence provides indicative evidence on factors affecting the consumer-to-prosumer evolution. Other key theories reviewed in this study include transition theories, diffusion of innovations, and different technology adoption models such as TAM (Davis 1985).

A conceptual model and a set of hypotheses are developed based on the theory review of diffusion of innovations (Rogers 2003) and TAM (Davis 1985). The TAM is then slightly modified for the purpose of the study. As the economic considerations of RET investment are of key concern to consumers, TAM's "perceived usefulness" is divided into two parts: "functional" and "economic" perceived usefulness. Furthermore, non-economic and economic policies are applied as "external factors" to the model.

A consumer survey in Europe (N = 197) is used for data collection. The measurement items for the conceptual model are configured in two phases. First, the survey items are mapped to the measurement items based on the diffusion of innovations and TAM theories. Second, principal component analysis (PCA) is applied to confirm the mapping of the measurement items into latent variables. Consumer survey data are then analyzed using PLS-SEM. Suitability of PLS-SEM for explorative research with relatively small sample size has already been discussed in the methodology and in the context of appended Article III.

The findings suggest that a broad set of policies influence the attitudes related to the adoption of RETs, including both economic and non-economic policy instruments. Furthermore, the findings propose that compared with economic policies, the total effects of non-economic policies could shape consumers' attitudes toward using RETs even more. The non-economic policies had a strong influence on "perceived ease of use" and "perceived functional usefulness." It also showed a moderate influence on "perceived economic usefulness."

Previous studies have found that "perceived usefulness" was a powerful predictor of system use (Surendran 2012). In this study, "perceived usefulness" included functional items that were related to the availability of services that allowed monitoring and using the system, the ability to independently adjust the system, energy autonomy, assessing information about electricity peak prices, and as a separate construct, financial benefits such as the ability to sell excess energy for guaranteed prices. The findings revealed that non-economic usefulness particularly affected consumers' attitudes. It is thus essential to emphasize the communicate of on the functionality benefits of RET solutions.

The analysis was conducted for both consumers (non-adopters) and prosumers (adopters). The results for prosumers were very different from those for consumers. The majority of the hypotheses regarding prosumers were rejected. The TAM was designed to model technology acceptance by non-adopters. Thus, the results show that prosumers expect different types of policies to support their actual use of RETs than consumers who have not yet adopted RETs.

The Article contributes to both theory and practice. Testing of the TAM model in the new context contributes to TAM theory and applicability in RET adoption. Empirical contribution of this research is related to the role of policies in RET acceptance and adoption. Research items related to the perceived ease of use were associated with the availability of ready-to-use solutions, the availability of the solution from a one-stop shop, and the easiness of installation. The findings showed that these items affected the consumer and prosumer attitudes toward using RETs, which suggests that designing turnkey solutions for RETs and focusing on ensuring their availability and delivery for consumers is important.

4.6 Article VI: Prosumer policy mix

This paper examines the policies that affect prosumer activities and proposes a conceptual framework for more systemic energy production and use, and a holistic approach to policies covering the sustainable generation of energy by prosumers.

Energy prosumers are increasingly using solar panels to generate a subset of their energy needs. At the same time, the number of EVs is increasing. EVs require energy for charging, and the sustainability of the electric transportation is dependent on the sustainability of the electricity produced. EVs can also be used as flexibility resources to the electric grid. The systemic nature of energy, transport, and buildings is enabling solutions that could induce benefits for multiple stakeholders. Similarly, if different prosumer activities are interlinked, more sustainable and economically viable results can be achieved.

This paper first reviews the key theories related to energy and transport sector transitions (Geels and Schot 2007), diffusion of innovations (Rogers 1995), and policies in the context of diffusion of sustainable technologies (Howlett and Ramesh 2003; Vedung 1998).

The following RQs are addressed in this paper: 1) How can microgeneration by small-scale prosumers and EVs together increase the sustainability of the energy system and 2) what policy mix would be required to support the combined EV–prosumer activity. To address these questions, EV- and prosumer-related technologies, sustainability factors, adoption challenges, and policies are discussed.

The paper reviews and maps the typical environmental policy instruments to different prosumer activities: micro-generation, DR, and EVs as storage and flexibility resource. Regulatory, economic, management and planning, information and education, and voluntary approaches are used to categorize the policies (OECD 2001). The policies related to EVs and prosumer activities are a result of different policy sectors: for example, energy and climate policy, industrial policy, tax policy, and transportation policy. Some policies are based on regulation, some on economic instruments, and some on soft policies or a mixture of these. EV policies are found to be less regulative than microgeneration policies, which are steered with command-and-control regulations. Table 7 presents the policy comparison.

Table 7. Policy comparison of electric vehicles, microgeneration, and demand response (Kotilainen, Mäkinen, et al. 2017) [4].

	Electric vehicles	**Microgeneration**	**Demand response**
Regulatory	Permit use of bus lanes Building codes and permits Tailpipe emission standards	Building codes Interconnection rules Self-consumption Collective self-consumption Priority dispatch System size limitations Smart meter rollout Third party ownership Certificates on technology and installations CO_2 emission restrictions (e.g., Kyoto protocol and EU-ETS) Restriction on product energy consumption (e.g., power limits)	Building codes and regulation on electrical installations Allowing market entrance for DR and aggregated load Product requirements such as minimum bid sizes and duration Communication standards and protocols Performance measurement Smart meter rollout Data protection Revising DSO regulation
Economic	CO_2 tailpipe tax Exemption from purchase tax, VAT Exemption from usage tax Subsidy on purchase price Exemption from road tolls	Exemption from self-generation tax Tax credits Reduced VAT Interconnection fees Network tariffs Self-consumption fees Investment subsidies Soft loans Feed-in tariffs and premiums Net metering and billing	Dynamic pricing Capacity-based network charges Dynamic taxes Avoiding fixed levies in electricity prices Penalties and financing requirements for aggregators
Management and planning	Investment in charging infrastructure R&D investments in battery technology development	Micro-grid management Balancing rules and responsibilities	Balancing rules and responsibilities Local flexibility trading Data management
Information and education	Free parking for EVs Information and education campaigns Public use of EVs Lead-users for EVs	Eco-labeling Energy saving campaigns Demonstrations	Smart home labels Demonstrations Campaigns and education Regulation on information about the contract Standardizing contract types
Voluntary agreements	EV clubs and associations Use of alternative transportation	Shareholder programs Green tariffs Energy saving (e.g., LED lights)	

[4] Unless otherwise indicated, the text is verbatim from Article VI.

Next, the paper outlines the framework to address the need to enhance EV sustainability through solar PV production and storage, technologies that are accessible by residential house-holds. In the framework, a prosumer produces emission-free energy using solar PV and uses it to charge the EV, stores it for later use in the EV battery or a home battery unit, and feeds it into the grid as a flexibility measure as needed.

The policy mix to support integrated prosumer activity is proposed for three key phases of technology diffusion. First, the policies need to support the technology adoption of RETs, such as solar PV, EVs, and smart meters. Energy self-generation needs to be promoted and supported. Market-based policy instruments can be used to incentivize the purchase decision of RET and regulatory instruments and ensure infrastructural readiness, such as availability of grid connection and smart metering. R&D investments are needed for the continuous improvement of charging technologies, batteries, and infrastructure. Second, the policies must enable the integration of RETs with the electricity grid through, for example, smart charging. Charging infrastructure deployment needs to be accelerated through the regulation of building codes and property laws and financial incentives. Third, the policies must incentivize active DR participation of the prosumers. Here, new business models and roles, such as an aggregator, need to be enabled. In addition, advanced pricing schemes and information dissemination of the DR benefits should be used.

This paper contributes to both the general sustainability transition research field and policy sciences research. The paper emphasizes the importance of systemic solutions to optimize novel technology solutions, such EVs and smart meters, by proposing a framework for integrating the energy prosumers with the use of these technologies, and the need for the policy support to implement the framework. Mapping of policies related to prosumer activity is another contribution of this paper. A more holistic policy approach to support the systemic and integrated solutions is one step toward policy mix that can support the different phases of technology adoption, integration, and use.

5 DISCUSSION

This section discusses how the appended articles contributed to answering the three RQs. First, RQ1 concerning the *enablers* discusses the research findings in general and then focuses on the perspective of *policy as an enabler*. Second, RQ2 focuses on the *activities*. The discussion is built around the findings concerning different prosumer activities, with special attention to the perspective of *innovation as an activity*. Third, findings related to RQ3 are discussed in light of sustainability transition, energy system, and energy innovations.

5.1 Enablers and activities of energy prosumers

Next, the article contributions to the RQ1 and RQ2 are discussed.

5.1.1 Enablers: What does it take to evolve from consumer to prosumer?

The first RQ addresses the energy prosumer enablers: A) How do different enablers contribute to consumers' evolution into prosumers? B) What is the role of policy as an enabler?

Ensuring that the necessary enablers are in place is the first step toward citizen engagement in the energy system. Based on the initial literature review, the enablers were narrowed down as policy, technology, economic, and individual factors (see e.g., (IEA-RETD 2014; Kotilainen 2019). Some of the enablers are prerequisites to produce, sell, or store energy. In general, many technology enablers are often such prerequisites: for example, solar PV enables energy production and batteries enable storage. Other enablers have a different role. Individual enablers related to motivations, attitudes, skills, and resources influence decision-making and behavior and determine whether the consumer will actually evolve into a prosumer (Masini and Menichetti 2013). Economic enablers increase the perceived benefits of prosumerism and hence support the decision-making. Designing suitable policy mixes in sustainability transitions was identified as one of the research gaps in the sustainability transition research agenda (Köhler et al. 2019). Policies can accelerate the prosumer base growth or, in some cases, slow it down (Rogge and Reichardt 2016).

The prosumer enablers fall in all levels of the socio-technical MLP (Geels and Schot 2007). Economic enablers concerning the market conditions and price levels are mainly coordinated by the regimes. Novel technologies emerge from the niche to complement, and eventually to replace, the existing systems (Schot et al. 2016). Policies are landscape and regime tools to induce and steer the change. While the analytical research framework recognizes different types of enablers and they are to an extent discussed in the appended articles, the appended Articles V and VI focus more closely on policy as an enabler.

The significance of policy mixes in sustainability transitions is clear, but the current policy mixes are far from perfect (see e.g., (Kotilainen, Aalto, et al. 2019; Rogge and Reichardt 2016). As discussed above, policy is a key enabler in removing obstacles from solar PV, EVs, and battery diffusion (IEA 2017; Ossenbrink 2017; Reddy and Painuly 2004), all of which require a substantial investment in RET. Examples of the effectiveness of FIT schemes in growing the small-scale solar PV base show how policy influence can be used to drive the adoption of sustainable technologies (Ossenbrink 2017). Concerning the technologies that have a high up-front investment cost, economic incentives are clearly in a key role in the consumer decision-making. However, besides economic incentives, policy influence has other aspects (Kahneman 2003). Article V analyzed the potential influence of economic and non-economic policies on consumer-to-prosumer evolution. The key finding here was that both economic and non-economic policy incentives are important for consumers considering the adoption of RETs. The supportive research stream, citizen survey (N = 1349), also found that the key barriers related to the consumers' willingness to adopt solar PV were economic but that other factors also influence their decision-making: for example, the availability of turnkey solutions, getting information about electricity consumption, independence from the grid, and reducing emission (Ruostetsaari et al. 2018). The results from Article V confirm the importance of these elements; hence, more holistic policy mixes covering the economic and non-economic aspects of decision-making are called for to accelerate the adoption of RETs (see also (Rogge and Reichardt 2016). RET adoption, for example, in Finland is slow compared to some other markets owing to the lack of targets and policy support for solar energy diffusion (Haukkala 2019; Ruostetsaari et al. 2018). Furthermore, strong EV incentives in Norway have enabled fast electrification of transport, whereas in Finland, where the incentives are modest, the

EV base growth is slower, with focus on PHEVs rather than BEVs (IEA 2018; Kester et al. 2018; Kotilainen et al. 2018).

Active prosumers, that Schot et al. (2016) call user-citizens, have found their place in influencing policy agendas both at the EU level and in many of its member states (European Commission 2009, 2017). Article VI observes how policies are currently applied to different prosumer activities, specifically microgeneration, DR (and storage), and energy sales. The article proposes that these should be treated as integrated rather than separate activities to obtain the maximum effects of small-scale prosumers' activities on sustainability. For example, if both solar PV and EVs are incentivized, the residential house-holds are able to produce clean energy to charge their EVs, rather than rely on the national energy mix, where fossil fuels are still likely to be used. Hence, the policy mixes should also be more holistic and encourage prosumers to engage in multiple activities rather than just one. For example, prosumers that produce energy could also use it to charge their EVs and participate in DR plans. Soft instruments such as information campaigns could be effective to partially achieve this; however, economic incentives to accelerate EV and battery diffusion are also required. To create such holistic policy mixes that support different actors, better coordination of policies between different policy streams in the policy goal setting, design, and instrument planning is needed, as suggested by Rogge and Reichardt (2016) in their framework for policy mixes for sustainability transitions.

Policy mixes also vary greatly even within the EU. The five-consumer survey (N=197) countries have both similarities and differences in their approaches e.g. to emission reduction and the policy mixes to support micro-generation, EVs, storage and other prosumer enablers vary by country. Germany supports solar micro-generation, storage and EVs but is behind in rolling out smart metering and advanced DR regulation. France is leading in EV support, DR and solar production but has does not have full-scale smart meter rollout nor strong battery incentives. Italy has traditionally supported energy efficiency, smart metering and solar PV production but has been slower in opening DR markets. Finland has open electricity market with smart metering infrastructure in place but is not particularly incentivizing micro-generation or residential battery storages. Switzerland is one of the front-runners in micro-generation and DR, but smart meter rollout is not completed and the market liberalization is also still under implementation. (European Commission 2017; IEA 2017; Valta 2017; B. Zhou et al. 2016). Further studies mapping the local policy frameworks and prosumption could be very useful in increasing the understanding of policy influence on consumer and prosumer decision-making.

5.1.2 Activities: Getting prosumers actively engaged in energy

RQ2 is linked to the energy prosumer activities: What are the core prosumer activities in the energy system? How do prosumers contribute to the adoption and co-creation of energy innovations? This is closely connected to the question of how to activate consumers and prosumers in the energy system–related processes. Deeper understanding of the prosumer activities may contribute to the pragmatic steps toward this objective highlighted in national energy and climate strategies (Ympäristöministeriö 2017).

First, the core activities were identified based on the European Commission's (2016) definition of "active consumers" as those involved energy production, sales, storage, and DR. In addition, this dissertation observed prosumers as innovators owing to the gaps identified based on the STRN research agenda (Köhler et al. 2019) and earlier research (Heiskanen and Lovio 2010; Hyysalo et al. 2013; Schot et al. 2016; Wittmayer et al. 2017). Hence the prosumers were observed not so much as citizen activists influencing the political agendas but rather as participants in the energy system and markets.

Second, Articles I and II propose that these prosumer activities fall in either the regime or niche level in the socio-technical framework. For example, DR is a regime-driven activity coordinated by incumbent utilities. Prosumers here are expected to be rather passive participants and play by the existing rules set by the incumbents. Technologies such as smart meters, automation, and remote monitoring and control enable DR management without any active intervention from the consumers (Haider et al. 2016a; Honkapuro et al. 2017; Martín-Martínez et al. 2016; Vanthournout et al. 2015). This can take pressure away from making changes to one's behavior, which has been seen as a barrier for DR (Jansson et al. 2008; Valles et al. 2016). Energy feed-in to the grid also operates based on the regime rules, but P2P energy selling is currently mainly taking place in niche experiments (Andoni, Robu, Flynn, Abram, Geach, Jenkins, McCallum, et al. 2019; Mengelkamp et al. 2018; Sousa et al. 2019). Innovation co-creation, addressed in Articles IV and V, typically is a niche activity, especially when initiated by individuals such as DIY customers (Cloutier et al. 2018; Fox 2014) or "user-producers" (Schot et al. 2016). Here, prosumers can play a very active role. Co-creation can also be initiated as a regime actor to produce enhancements to current offering. Furthermore, energy storage and EVs are still at the niche level in many markets (Barbour and González 2018; IEA 2017). Here, the focus is currently on boosting the adoption of EVs, which is closely linked to developing suitable policy mixes.

Third, prosumers are observed through separate activities, such as solar PV energy production. However, moving forward, a more systemic approach would be beneficial, as discussed in the appended Article VI; by combining the production, storage, and grid integration of prosumers, the sustainability benefits of these activities would be enhanced, more efficient use of RESs would be possible, and more RESs would be used in general (see also (Kotilainen 2019). In fact, this is maybe where energy prosumers and their role in the industry most differs from other types of prosumers, such as the social media content providers: the value they bring to the energy industry increases through their ability to contribute in more than one way.

Fourth, *prosumers as innovators* was selected as a perspective for this dissertation and Articles III and IV focused on studying prosumers as co-creators of energy innovations. In addition, Articles I and II identified prosumers as innovation adopters and participants in innovation activities in the emerging energy ecosystem. The role of user innovations and co-design was identified as one of the research areas in STRN's agenda (Köhler et al. 2019). Micro-foundations of the innovation activities were studied in the appended Article IV. The results of Articles IV suggest that there are differences between consumers and prosumers in terms of their personal characteristics, attitudes, needs, and motivations. First, based on the results, prosumers seem to exhibit early adopter characteristics to a greater extent than the consumers that have not yet adopted RETs. Furthermore, Article V contributes to the understanding of prosumers as innovation (RET) adopters. Prosumers' role as innovation adopters is important as RETs are required in order to produce and store energy. Prosumers were considered to be early adopters based on Rogers' diffusion of innovation theory (Rogers 1995), meaning that at least some of them are technology enthusiasts that like to test new technologies and accept immature solutions even at high costs. However, when the mass market starts adopting RETs, they will require easy to access and own solutions that are affordable and reliable, putting pressure to the development of more systemic turnkey solutions and services.

Fifth, prosumers could contribute to the generation of grassroots energy innovations in multiple ways (Hossain 2016; Klein and Coffey 2016). These activities are driven by individual motivations and personal characteristics, as discussed in appended Articles III and IV. Article III shows that both consumers and prosumers are generally interested in co-creation. However, their preferences are skewed toward the later phases of NPD: demonstration and commercialization, meaning that they like to test products and services before commercial launch, give feedback, and also validate business models but are less keen on participating in the ideation and development. Rogers (1962) fairly points out that innovators (as an adopter group) are not necessarily "inventors." Overall, the importance of experiments is widely recognized in recent studies on sustainability transitions (Heiskanen et al. 2018).

5.1.3 Summary of the activities and enablers

The above and earlier discussed prosumer activities and their enablers are summarized in Table 8.

Table 8. Summary of typical energy prosumer activities and their key enablers.

	Activities:				
Enablers:	Production	Sales	Storage	Demand response	Innovation co-creation
Technology	Solar PV, small-scale wind turbine, biomass processor	Market place Blockchain Grid connection Smart meter Digital market place	EV Home battery Thermal storage	Solar PV Smart meter, HEMS Electric space heating system, water heating boiler Heat pump EV Home battery	Crowdsourcing platform Company extranet OSS toolkit Discussion forum Online community
Economic	Saving in energy bill RET price Investment payback time	Electricity price	Electricity price EV price Battery price	Economic incentives Savings in energy bill	Economic rewards
Policy	FIT Net metering Tax exemption Building codes Regulations	FIT Net metering Taxes and fees Grid connection Regulation Energy market rules and regulations	Subsidy Tax exemption Priority lane use (EV) Free parking CO_2 taxation	Dynamic tariff structures Incentive-based schemes Smart metering mandate Market rules	Funding for demonstrations and experiments
Individual (other)	Housing type Environmental attitude (Solar radiation)	Knowing the origin of energy		Available resources Perceived comfort Environmental attitudes	Motivation Improvement needs Technical skills Personal characteristics Environmental attitudes

5.2 Prosumers: Their role in transition?

RQ3 is concerned with the role of prosumers as part of the energy transition: *What is the prosumers' role in energy transition and how do prosumers influence the transition?* This RQ addresses the identified gaps related to the lack of single-actor research in addition to systemic studies and the need to better understand the influences of actors in the wider context (Köhler et al. 2019; Schot et al. 2016; Wittmayer et al. 2017).

As established in studies related to the socio-technical MLP (Geels 2012; Geels et al. 2019; Verbong and Geels 2010) and SNM (Schot and Geels 2008), sufficient pressure from both landscape and niche is required to fuel up regime shifts. Once the transition progresses, regime gets more and more involved in the change. The research framework already made pre-assumptions about the prosumer role at the high level; prosumers were considered as actors that are enabled by technology, economic, policy, or individual factors and that engage in activities such as energy production, sales, storage, DR, and innovation co-creation that in turn influence the transition. These activities influence the sustainability transition of the energy and contribute to the value along with other actors in the energy ecosystem (Talmar et al. 2018; Wittmayer et al. 2017).

Articles I and II observed prosumers in the socio-technical MLP (Geels and Schot 2007) and smart grid innovation ecosystem, respectively. Prosumers were considered as actors that participated in different activities, which in turn launched potentially new bottom-up trajectories for the energy regime change at the same time as the macro-level policy pressurized the regime from the top. In this dissertation, and especially in the appended articles, the energy prosumers were observed not so much as citizen activists (user-citizens, Schot et al. 2016) but rather as active participants in the energy system and markets. This research dived into different aspects of the energy prosumers through their enablers and activities and from there attempts to increase the understanding of the prosumer role in the energy system transition.

To influence the transition and accelerate it, the prosumer base must be substantial (Foxon and Pearson 2008; Hillman et al. 2011). Prosumer base growth has taken different paths in different markets; examples of Germany and the UK having a large number of residential prosumers have already been discussed (European Commission 2017). On the contrary, Finland still has a small prosumer base (Ahola 2019). Scenarios built on the basis of expert interviews[5] on the prosumer role development in the Finnish energy system in the next ten-year horizon proposed

[5] As part of the ProCem project in 2017.

that the prosumer base growth would bring both benefits and challenges to the Finnish energy system. The benefits were seen in the form of increased amounts of RES and DG and new business opportunities. The main concerns related to mass prosumerism included a perceived threat of out-of-control micro-grids that could destabilize the entire electricity system, business challenges to the existing energy sector companies, and a potential off-grid movement led by the consumers. It was considered unlikely by the experts that the prosumer base will rapidly grow in Finland over the next 10 years. This is at least partly attributable to the fact that Finland does not currently offer strong incentives, such FIT, to solar PV energy production. Moreover, there are no official targets to increase the solar energy production (Haukkala 2019). The experts agreed that the "prosumerism stalls," in which the prosumer base slowly increases but still remains marginal from the energy systems point of view, is the most likely scenario in Finland during the time frame and in the current regulative environment.

First step to prosumer base growth is adoption of the technology enablers. This is directly linked to e.g. solar PV and EV diffusion. Article V focused on understanding the policy influence on RET adoption and found out that having a policy mix that consist of both economic and non-economic incentives is important.

While the prosumer base development in some markets may be slow and uncertain, once the prosumer base is sufficiently large, it starts to have an impact on the energy transition. These potential effects are discussed in light of sustainable development, energy systems and markets, and energy innovations.

Sustainability is considered to include economic, environmental, and social aspects (WCED 1987). How does prosumerism influence these three key areas of sustainable development? First, environmental sustainability is a macro-level concept that is closely related to the climate change mitigation. Prosumerism can contribute to environmental sustainability in multiple ways (see e.g. (Blättel-Mink 2014; Kotilainen 2018, 2019; Park et al. 2018)). For example, increasing DG of energy based on RES has a positive impact on emission reduction (Kohtala 2015). If the prosumer base is large, prosumerism significantly increases the share of renewables in the energy system and helps in mitigating climate change in the form of reduced emissions. Prosumerism can also contribute through improved energy efficiency. In case energy efficiency is considered to include the concept of peak demand reduction, and especially when the battery storage technologies become more widespread, lowering overall demand and allowing roll-out of better flexibility schemes becomes feasible (Barbour and González 2018; Olinsky-Paul 2019). Second, social sustainability is a broad concept, and community resilience is one of the factors used to measure it (Magis 2010). Access to affordable energy can lead to improved resiliency in communities and has a positive impact on people's livelihoods. Energy production using solar PV, wind turbines, or biomass processors could dramatically change the situation in rural communities that currently do not have access to the electricity grid (Magis 2010). Third, economic sustainability can be improved when new business models involving prosumers become mainstream (Sandoval and Grijalva 2016). Prosumers' opportunities to sell energy to consumers enable savings and additional income. After recuperating the initial investment of solar PV, locally produced and consumed energy is highly affordable (Wolske et al. 2017).

Energy system influences of prosumerism, including both technical and commercial impacts, were already discussed in Chapter 2. Increased decentralization and variable energy production challenge the electricity grids in their current form (IEA-RETD 2014; Kiviluoma et al. 2018). More flexible ways of producing and using energy are needed to overcome these obstacles. The importance of DR is emphasized at the consumption end. Similarly, the position of incumbent energy firms and regime rules are challenged. Prosumers as part of the smart grid innovation ecosystem were discussed in appended Article I and the changing industry dynamics were discussed in Article II. This dissertation did not, however, focus on understanding the technical challenges related to prosumerism, a topic that has already received substantial amount of attention in other studies (Gensollen et al. 2018; Malamaki et al. 2017; Pasetti et al. 2018; Qiu et al. 2018)

Energy markets also feel the pressure to change as new business models that are enabled by the digitalization of the energy system emerge. For example, new types of market places for small-scale producers are likely to emerge as regulation is gradually adjusted to meet the needs of changing requirements. The role of micro-grids and energy communities in the energy markets need to be better understood. New actors and roles, such as aggregators, are also emerging. The changes require market rules and legislation to be updated (TEM 2018). Article II focused from the socio-technical MLP into the smart grid innovation ecosystem, where different actors were positioned along with the prosumer. The article concluded that creating systemic innovations requires close co-operation between incumbent and new stakeholders, which can be challenging owing to different "clock-speeds" of ICT and energy companies. Finding the common "mission" may be time-consuming and currently, prosumers are less than integrated into the energy system processes.

In Article II, prosumer influence on *energy innovations* was explored through the development of digital layers through which the prosumers engaged with other actors in the ecosystem. These activities were proposed as different types of ecosystem-level innovations such as functionality improvements, innovative services, and new innovative processes. Consumers and prosumers are also known as DIY users because they could come up with new innovative functionalities (Cloutier et al. 2018; Fox 2014; Wolf and McQuitty 2011). However, especially user-centric electricity innovations are still rare, partially due to fact that the electricity markets are still regulated and there are many aspects that are off-bounds for other than qualified electricians or authorized organizations (Heiskanen and Matschoss 2011). On the other hand, there are more innovation examples related to solar PV (Ornetzeder and Rohracher 2013) and home energy technologies such as heatpumps (Hyysalo et al. 2013). Energy communities are currently emerging in Europe, which could further increase the grassroots innovations (Klein and Coffey 2016). Working with prosumers could help businesses improve and mature their solutions and be ready to convince the mass-market adopters that require easy solutions. Articles III and IV developed the understanding of prosumers as innovators and value-creators. The research showed, for example, that consumers and prosumers are interested in different types of innovation activities, especially in the demonstration and commercialization phases of NPD, and that they are mostly motivated by intrinsic factors. Intrinsic motivations also have been suggested to be more effective in steering long-term behavior in earlier research (Clark et al. 2003; Füller 2010; Kotilainen, Mäkinen, et al. 2016; Ryan and Deci 2000).

5.3 Article contributions to the research questions

Table 9 summarizes the appended articles' main contributions to the RQs discussed above and in Chapter 4.

Table 9. Summaries of the article contributions to the research questions.

Article	RQ1: enablers	RQ2: activities	RQ3: transition
I			Prosumers were positioned as part of the socio-technical MLP (Geels 2002; Schot et al. 2016). Propositions to address the prosumer role in smart grid systems were developed.
II		Digitally enabled innovation opportunity areas of prosumer collaboration were proposed.	Prosumers were positioned in the propositional digital energy ecosystem with other actors. Barriers for prosumer base growth were outlined in light of regime inertia.
III		Consumer and prosumers were found to be interested in different collaboration activities. Prosumer interest in innovation co-creation was confirmed to be skewed toward the later stages of the NPD process. Incentives based on intrinsic rewards were emphasized.	
IV		Micro-foundations of the consumer and prosumer interests to collaborate were identified as early adopter characteristics, improvement needs, and intrinsic rewards. Differences between consumers and prosumers were identified.	
V	TAM was adapted and applied in the context of energy policy. A broad set of policies were confirmed to have an influence on the consumer attitudes toward RET adoption. Role of non-economic policies were emphasized. Consumers and prosumers were discovered to differ in their attitudes.		
VI	Sustainable prosumer–EV framework was proposed. Mapping of policies to different prosumer activities was conducted. The results call for more holistic policy mixes to address prosumer activities.		

6 CONCLUSIONS

The final chapter of this dissertation summarizes the contributions to theory and practice, runs a quality assessment and discusses both limitations and future research avenues.

6.1 Contributions to theory and practice

This dissertation investigated energy prosumers through their activities and enablers and attempted to build links of these to the level of socio-technical MLP, innovations, and policy. The aim of this dissertation was to paint a holistic picture of the energy prosumers as part of the energy transition; this type of understanding was largely missing when the research was started in 2016. Next, both theory and practical contributions of this dissertation are summarized.

6.1.1 Theory contributions

The multidisciplinary approach to increasing the understanding of energy prosumers involves several research fields. Next paragraphs and Table 9 summarize the key theoretical contributions of the research in general level.

First, this study contributes to the sustainability transition research. A single actor, the energy prosumer, is observed in the context of socio-technical transition of the energy system. The results contribute to the MLP and SNM studies focusing on actor roles in the transitions, such as Schot et al. (2016) description of the users in transition. Where Schot et al. focus on identifying different types of prosumers at different phases and levels of the socio-technical change, this dissertation observes in more detail the energy prosumers' enablers and activities and contributes the understanding the impacts of these elements to the overall transition. Prosumer role is furthermore explored in the socio-technical system in Articles I, II, and VI. Novel analytical research framework is then built to guide the dissertation research based on the socio-technical MLP (Geels and Schot 2007) and on the adapted version of the intra-actor ecosystem value-creation framework (Talmar et al. 2018). Article II presents a propositional framework for prosumer-centric digital energy innovation ecosystem combining the socio-technical MLP, actors, and elements of different ecosystem models (Geels and Schot 2007; Oh et al. 2016). Furthermore, Articles II, III, and IV contribute to the grassroots innovation studies connected to the sustainability transition research agenda's theme "civil society, culture, and social movements in transitions" (Köhler et al. 2019).

Second, this dissertation contributes to the theories related to innovation studies, especially in the field of user-centric innovations, by proposing new research results for understanding the factors behind consumer and prosumer collaboration interests in energy-related initiatives. Article I proposes prosumers to be primarily early adopters (Rogers, 1995), and Articles III and VI further elaborate this proposition. Empirical results in Article IV confirmed that prosumers exhibit early adopter characteristics more than non-prosumers. Furthermore, the understanding of the consumer and prosumer preferences for rewards from the perspective of co-creation is further extended. The analysis confirms the importance of intrinsic motivation in rewarding co-creation (Amabile, 1996; Füller, 2010; Ryan and Deci, 2000). Article III also contributes to the understanding of co-creation interests in light of the NPD process (Cooper 2014): interests are skewed toward the demonstration and commercialization phases rather than pre-NPD and development phases. Another theoretical contribution is made in Article V, wherein the conceptual model based on TAM (Davis 1985) is adapted and tested in the context of RET acceptance. Moreover, Article II focuses on understanding different aspects of digitally enabled energy ecosystem in which prosumers are focal actors. Article II emphasizes the systemic nature of the energy transition and exemplifies the needed multi-disciplinary research combining innovation ecosystem, end user role, complex industry transitions and new technology platforms together.(Kotilainen, Sommarberg, et al. 2016)

Third, theoretical contributions to policy studies are two-fold. First, the analysis results of the typical policy mixes used in the context of different prosumer activities contribute to the policy studies. Policy mix analysis in Article VI calls for a more holistic policy mix approach to cover different prosumer activities (Howlett and Ramesh 1995; Rogge and Reichardt 2016) to maximize the benefits of prosumerism in the different phases of prosumer base development: adoption of RET, integration of prosumers into the grid, and prosumer participation support in flexibility schemes. Second, the policy influence on consumer attitudes toward adopting RET is analyzed in Article V. The findings call for a broad set of policy instruments including both economic and non-economic incentives.

Table 10. Summary of the theoretical contributions related to the research questions and analytical focus.

Article	Analytical focus	Theoretical contribution
I	Understanding prosumer position in the socio-technical MLP (Geels and Schot 2007) in the Smart Grid innovation ecosystem context. Proposition development for the prosumer role in the smart grid innovation ecosystem. *Sustainability transition studies, Innovation studies*	Positioning the prosumer on the niche and regime levels of the socio-technical MLP (Geels and Schot 2007; Schot and Geels 2008) contributed to the development of the analytical research framework for the dissertation. Propositions are generated to further explore prosumer role in the innovation ecosystem. Proposing energy prosumers to be primarily early adopters at this stage contributes to the diffusion of innovations theory (Rogers 1995). The propositions contribute to co-creation studies e.g. (Prahalad and Ramaswamy 2004). Propose both macro and micro level factors affecting the energy prosumers.
II	Developing a framework for a digital energy innovation ecosystem based on socio-technical MLP and different ecosystem models. Understanding the changing industry dynamics of the energy sector. *Sustainability transition studies, Innovation studies*	The framework for prosumer-centric digital energy innovation ecosystem combines the socio-technical MLP, new and incumbent energy actors, and elements of different ecosystem models at the same time contributing to different strands of ecosystem studies e.g. (Adner 2006, 2017; Briscoe 2010; Chang and West 2006; Nachira 2006; Oh et al. 2016; Talmar et al. 2018; Walrave et al. 2018) Prosumer (ecosystem) barriers are mapped based on theoretical frameworks of Porter's five forces, missing systemic factor , perceived and natural inertia , bounded rationality (Dosi 1982; Hacklin et al. 2010; Metcalfe 2013; Porter 2008; Prahalad and Bettis 1986) .
III	Analysis of the consumer and prosumer interest and motivation toward co-creation *Innovation studies, Sustainability transition studies*	The results confirm that both consumers and prosumers are generally interested in collaboration activities. The results confirm the importance of intrinsic motivation in rewarding co-creation (Amabile 1996; Füller 2010; Ryan and Deci

		2000) and contribute to the understanding of co-creation interests in light of the NPD process (Cooper 2014): the interests for collaboration are more skewed towards the latter phases of NPD. Grassroots innovation studies also gain understanding of the consumer and prosumer co-creation interests (Hossain 2016).
IV	Design and analysis of a conceptual model of micro-foundations of collaboration interest, Innovation studies *Innovation studies, Sustainability transition studies*	Proposing micro-foundations of collaboration interests for sustainable user-centric innovations (Ornetzeder and Rohracher 2006; Rogers 1995) to be related to early adopter characteristics, intrinsic rewarding and needs for improvements. Grassroots innovation studies also gain understanding of the drivers behind co-creation interests (Hossain 2016).
V	Design and analysis of a conceptual model for understanding how policies influence consumer attitudes toward prosumption *Innovation studies, Policy studies*	The conceptual model contributes to TAM studies by adapting the model by dividing "perceived usefulness" into two parts, applying policy as an external factor, and testing the adapted model in the RET context (Davis 1985). Both non-economic and economic policies are found to influence the consumer attitudes toward adopting RES, with slight emphasis on the non-economic policies.
VI	Proposing a framework for SEP integration. Analysis of a typical policy mix related to prosumer activities *Policy studies*	Policy mapping of typical policy instruments to microgeneration, demand response and electric vehicles. Policy mix analysis calls for a more holistic policy mix approach to cover different prosumer activities (Howlett and Ramesh 1995; Rogge and Reichardt 2016).

6.1.2 Practical relevance

Prosumers are new actors in the energy system that can potentially have a disruptive effect on how energy is produced and consumed in the future. Prosumers are also customers of solar PV manufacturers and distributors, EVs, smart meters, and HEMS. The practical relevance of the findings of this dissertation hence concerns *multiple stakeholders in energy*; energy industry incumbents, renewable energy companies, RET and EV manufacturers, service providers, and ICT firms benefit from the increased understanding of the prosumer enablers and drivers, activities, and potential influences on the energy system and market. See Table 11.

Table 11. Summary of the findings and their relevance to practice and policy.

Stakeholder group	Findings from the research	Relevance to practice	Article
Energy sector actors	Differences between consumers and prosumers	Increased understanding of prosumers for those designing products and services and developing business models	I, II, III, IV, V, VI
			I, IV
	Many prosumers are early adopters		I, V, VI
	Need for turnkey solutions		I, V, VI
	Need for new business models		II, IV
	Consumers and prosumers interested in collaboration and value co-creation	Prosumers could contribute to the development and testing of of novel solutions	I, II, III, IV
	Importance of intrinsic rewards	Monetary rewards are not optimal to motivate prosumers to collaborate	III, IV
Policy-makers	Need for economic and non-economic policies to support consumer-to-prosumer evolution	Design a broad set of policies to support prosumption. Non-economic incentives could accelerate RET adoption by improving ease of use and making turn key solutions available	V
	Need for a holistic and systemic policy mix to systematically	Holistic policy mix design could support prosumption in different activities from technology adoption to use and integration to the energy system to gain better sustainability benefits	VI
	Need for prosumer strategy and policy mix to develop prosumer base	Target setting and incentives for solar energy production	Dissertation
Other stakeholders	Holistic review of energy prosumers	Increased understanding of prosumers	Dissertation

First, improving the understanding of prosumer enablers and activities allows companies to prepare for increasing DG by small-scale producers. The findings in Articles III, IV, and V suggest that there are differences between consumers and prosumers. Recognizing this fact when marketing solar PV products or EVs can help businesses to better focus their efforts. The findings in Article V suggest that turnkey solutions increase the perceived ease-of-use and could lower the threshold to adopt complex technology solutions. Yet, one-stop shops are to a large extent missing. This type of understanding is needed from the perspective of accelerating the diffusion of RETs and preparing for their mass-market diffusion.

Second, new business models are needed to adapt the energy markets to meet future requirements. Prosumers will be participating in the markets in the future along with other new entrants, such as aggregators. However, market places, tariff structures, and value propositions require much more work before effective small-scale producer markets are operative. There will be opportunities to work with prosumers to design and test new business models, as suggested in Articles I and II.

Third, consumers and prosumers are generally interested in innovation and value co-creation, as established in Articles III and IV. Companies developing products and services for energy consumers could tap into this potential and involve prosumers in developing and testing novel solutions. Some of the innovators or early adopter type of prosumers could also ideate new functionalities and participate in co-development. Getting prosumers active in one area could lead to their active participation in other areas.

Policy-makers is another group that benefits from the findings. First, findings in Article V highlight the importance of having a broad set of policies covering both the economic and non-economic policy aspects of RET adoption. For example, economic incentives (such as FIT) and subsidies are important to accelerate prosumer base growth because RETs and EVs require substantial financial investment. Supporting the development and deployment of turnkey solutions should be in focus as the mass-market adopters start to consider prosumption.

Second, Article VI's analysis on prosumer-related policy mixes reveals that policies are still made in silos and no holistic approach is in place to support prosumers. The benefits of increasing prosumption are greater if different prosumer activities are integrated in a systemic manner. For example, prosumers could be encouraged to acquire EVs and utilize solar PV production to charge the batteries. Information campaigns about prosumption benefits to the environment are still rare but could be easily implemented.

Third, to activate the consumers to evolve into prosumers, it would be important to have a clear answer to the question "do we—or do we not—want to increase solar energy production in a decentralized set up?" For example, in Finland, there is no clear strategy for solar energy production and no incentives from both small and large stakeholders (FinSolar 2019). The solar PV production gradually increases, but it could be dramatically accelerated if more decisive policies were in place.

Consumers, consumer advocating groups, and *other stakeholders* may also benefit from the findings in this dissertation as it provides an overview of prosumers, prosumption activities, and required enablers as well as discusses prosumers in the context of the changing energy system. Table 11 summarizes the contribution to key stakeholder groups.

6.2 Reliability and validity considerations

This chapter assesses the quality of the research covering the entire dissertation and research process. The research was mainly conducted in two research projects (ProCem and EL-TRAN) and used mixed methods to explore a novel phenomenon of energy prosumers.

When I started the research in January 2016, prosumer-related academic papers were still mostly published in conference proceedings and industry reports were limited. The explorative research approach is well-suited when investigating a novel phenomenon that may also be complex and dynamic in nature. However, validity and reliability assessment in explorative research is not well-established. Some of the validity concerns when conducting explorative research are related to bias and lack of quality data, wherein the researcher must make assumptions that may not be based on facts.

Another aspect concerning the quality assessment of this research is related to the mixed methods approach. Onwuegbuzie and Johnson (2006, p. 48) state that "in mixed methods research, wherein quantitative and qualitative approaches are combined, discussions about validity issues are in their infancy." Indeed, quantitative research has widely scrutinized methods and frameworks for evaluating research validity. On the contrary, in qualitative research, validity is not that well-formed and consistently agreed upon, owing to which different typologies and terms have been proposed and are being used (Creswell and Plano Clark 2017; Eriksson and Kovalainen 2008).

The validity, also called legitimacy, in mixed method research can be assessed via three main strategies: 1) generic research approach, in which the validity of the mixed method research is assessed as a whole using generic tools; 2) individual components approach, in which validity is separately assessed for the quantitative and qualitative parts of the research; and 3) mixed methods approach, for which various mixed methods quality frameworks have been proposed to address the challenge of measuring reliability, validity, and generalizability (Creswell and Plano Clark 2017). I apply the second approach in this quality assessment.

6.2.1 Assessment of the qualitative research validity and reliability

Qualitative research assessment can be used to assess the overall research process as well as Articles I, II, and VI that were based on qualitative data. In qualitative research, a possible approach is to focus on the "trustworthiness" of the research (Eriksson and Kovalainen 2008). Lincoln and Egon G. Guba (1985) propose four criteria for establishing the trustworthiness of research: credibility, dependability, confirmability and transferability. Out of these, credibility and confirmability focus on the internal validity of the research, dependability on reliability and transformability on the external validity. In addition, generalizability of the research is used to evaluate the external validity of the qualitative research.

Credibility evaluates whether the researcher has credibility of the topic and whether data are sufficient to merit the claims (Eriksson and Kovalainen 2008). While my own experience on electricity systems and prosumers was limited in the beginning, research was conducted under the supervision of experienced professors representing four different research fields: electrical engineering, operational management, industrial engineering and management, and politics. In addition, research was conducted in two research projects (ProCem and EL-TRAN) that had multi-disciplinary teams. The research papers were critically reviewed both in the research project and by experienced co-authors. My educational background from industrial engineering and management as well as professional experience in innovation management and ecosystems in the international settings also ensured competence to tackle the tasks related to the innovation aspects of the research. *Confirmability* refers to linking the findings and interpretations to the data in a way that they can be easily understood (Eriksson and Kovalainen 2008). Developing analytical and conceptual frameworks based on well-known concepts also helps in addressing confirmability aspects. In addition, the development propositions and hypotheses strongly relied on literature and theory reviews, and these links were addressed in the respected articles. *Dependability* evaluates whether the research process has been logical, traceable, and documented (Eriksson and Kovalainen 2008). The next paragraph discusses the documentary review quality.

Transferability refers to establishing a connection between the current research and earlier research (Eriksson and Kovalainen 2008) and is typically considered to observe the external validity of the research. This was addressed using documentary review as a research method to establish strong links to earlier research and building analytical and conceptual frameworks to address the RQs. The documentary reviews were of multi-vocal nature as the goal was to address an actual and complex phenomenon, create hypotheses, and contribute to the knowledge. In multi-vocal reviews, typically, a broad set of different documentary sources are used. As this types of reviews are often explorative in nature, the quality criteria used in explorative case studies have been suggested to be suitable in this setting (Ogawa and Malen

1991). *Reviewer bias* is always a concern when conducting documentary reviews. The bias has three major sources: a) potential exclusion of documents, b) selectively ignoring some information, and c) accidentally overlooking information (ambiguous process) (Ogawa and Malen 1991). Research rigor was applied to ensure high-quality reviews. To achieve this, multiple sources of documents were consulted, records of the literature were maintained, and the articles were written in collaboration with multiple researchers. The materials and methods were also documented and stored in the project wiki sites.

Semi-structured expert interviews were conducted to support the integration of the research results. Special quality challenges related to this type of research are reliability, bias, and generalizability (Saunders et al. 2009). Concerning *reliability*, the interview data collection is often linked to time and space and not necessarily intended to be repeated (Marshall and Rossman 1999). In this research, interviews were used to explore an actual, complex, and dynamic phenomena in Finland. Should the interviews be repeated in a different setting and at a different time, the answers are very likely to be different. *Researcher bias* also affects data collection in interviews. The bias was addressed in the interview design and implementation. For example, the RQs were internally reviewed with the ProCem project group, the interview plan was sent in advance to the interviewees, all interviews were schedule to last for two hours, and the questions were explained as coherently as possibly to the interviewees. After the interviews, the notes were sent to the interviewees for checking and commenting.

Generalizability , also an indicator of external validity, was addressed through conceptual clarity and interpretive rigor (Toye et al. 2013). One of the key determinants of the conceptual clarity was the literature review on prosumer definitions and articulating their role in the socio-technical change. Inductive interpretation of data and results in the context of the analytical framework based on well-established earlier theoretical concepts and earlier research was supporting the interpretative rigor of the research.

6.2.2 Assessment of the quantitative research validity and reliability

Quantitative analyses of the research based on a consumer survey (N = 197) were discussed in Articles III, IV, and V. *Validity* determines how accurately the concept is measured (Heale and Twycross 2015). The commonly used criteria for addressing *internal validity* in quantitative research include three elements: content validity, construct validity, and criterion validity (Creswell and Plano Clark 2017; Heale and Twycross 2015; Saunders et al. 2009). Articles IV and V used PLS-SEM as the main analysis method. The validity assessment in PLS-SEM is typically performed in two steps: 1) assessment of the measurement model and 2) assessment of the structural model. Assessment of the measurement model focuses on addressing the validity of the constructs (mainly construct validity), and the assessment of the structural model focuses on the hypotheses and prediction power of the model (mainly criterion validity). These assessments are addressed in detail in the respective articles and briefly commented upon in the paragraphs below.

Content validity refers to how well the survey measurements can cover the research questions (Saunders et al. 2009): all relevant parts of the subject need to be addressed to produce valid results. To improve content validity, researchers can, for example, have other researchers or experts reviewing the research instruments and data and adjust these based on their feedback. In the survey design phase, the survey questions were created in a research group comprising four researchers. One challenge related to content validity is that the survey is quite broad (79 questions) because data were collected to cover multiple RQs. The questions were designed based on well-established theoretical concepts and empirical results from earlier research. To tackle content validity arising from potentially unclear or misleading questions, the survey was tested with a small group of randomly selected respondents, after which some of the questions were modified.

Construct validity refers to how well the measurements actually measure what they are intended to measure (Saunders et al. 2009). Potential pitfalls relate to, for example, hypothesis guessing, bias in experimental design, research expectations, confounding variables, and too narrowly defining the predicted outcome (Trochim and Donnelly 2001). Regarding the methodological choice to use PLS-SEM in Articles IV and V, a *PLS-SEM bias* refers to the PLS-SEM parameter estimates that are not optimal in terms of bias and consistency. However, the bias is often of minor relevance because the differences, as compared with other methods, are at a low level (Hair et al. 2011). Collinearity of the structural model was assessed using collinearity statistics; the values were found to be in line with the recommendations. In the PLS-SEM method, construct validity is assessed by testing convergent validity and discriminant validity (Hair et al. 2011). *Convergent validity* tests whether the measurements that should be related are actually related. Conversely, *discriminant validity* tests whether the measurements are unrelated. Average variance extracted was one of the indicators used to test the convergent validity in both articles using PLS-SEM. Heterotrait–monotrait (HTMT) correlations and the Fornell–Larcker criterion were used to assess discriminant validity. The results of the validity checks were in line with the recommended criteria, as explained in the respective articles.

Criterion validity (or predictive validity) means how well the survey questions can make predictions of, for example, future buying behavior (Saunders et al. 2009). The assessment of the structural model in PLS-SEM typically uses R^2 and path coefficients as the measures to test the underlying hypotheses and the predictive capacity of the model. The capability to predict can also be tested using Stone-Geisser Q^2 value. Both R^2 and Q^2 (using PLSPredict (Shmueli et al. 2016) in Article IV) values were analyzed and the predictive relevance of the models was found to be good.

Reliability is related to the replicability and consistency of the research and questions whether the research would provide similar results if repeated (Saunders et al. 2009). Stability (test re-test), internal consistency (homogeneity), and equivalence (e.g., alternative forms) are some of the commonly used reliability measures in survey research (Heale and Twycross 2015; Saunders et al. 2009). Cronbach's alpha is commonly used to test *internal consistency*. Cronbach's alphas were assessed in both articles using the PLS-SEM method. Moreover, composite reliability (CR) was tested because it is recommended to be used in PLS-SEM studies as an indicator of internal consistency (Hair et al. 2016). *Equivalence* was tested by making the survey available both via face-to-face contact and online. We did not find significant differences in the responses. *Stability* was not tested using the test re-test method—that is, by asking the same respondents to fill the survey twice—because the data collection method did not allow for contacting the same respondents again.

External validity, or generalizability, of quantitative research can be addressed e.g. through proper sampling and proximal similarity (Campbell 1986). *Sampling* method in the consumer survey was non-probability purposive sampling. The method was selected as there was a need to ensure that both prosumers and non-prosumers were represented in the sample. Due to the chosen sampling method, the results could be generalized to another groups of prosumers and non-prosumers, but not to the population in general. In the supporting research stream, citizen survey, random area sample was used. The result of this survey could be generalized to population of 18-75 year olds in Finland. Sample size also affects the generalizability. In the small consumer survey (N=197), the use of PLS-SEM and bootstrapping functionality simulates a much larger sample and hence improves the generalizability of the results (Hair et al. 2011). Another way to evaluate external validity in quantitative research is through *proximal similarity*, i.e. use heterogenous population and collect data in different times. The data collection was done in five markets in order to increase the heterogeneity of the sample. The collection was done in two main phases; first in France, Germany, Italy and Switzerland and about six months later in Finland.

Table 12 summarizes the key concepts used in internal and external validity and reliability assessments for both qualitative and quantitative research streams as discussed above.

Table 12. Summary of the quality assessment

	Type	Criterion	Method of testing	Measurements / tests
Qualitative research	Internal validity	Credibility	Researcher and data	Project work, data collection
		Confirmability	Link findings to data	Analytical frameworks, triangulation
	External validity	Transferability	Connect to earlier research	Theoretical frameworks and documentary review, triangulation
		Generalizability	Conceptual clarity	Articulating the concept of energy prosumers
			Interpretive rigor	Inductive interpretation of data and results in the context of the analytical framework
	Reliability	Dependability	Process	Records of the literature, archiving of data
Quantitative research	Internal validity	Content validity	Covering research questions	Pre-testing of survey
		Construct validity	Convergent validity	AVE
			Discriminant validity	HTMT correlations, Fornell–Larcker criterion
		Criterion validity	Predictive validity	R2, path-co-efficient, Stone-Geisser Q2 value
	External validity	Generalizability	Sampling	Non-probability purposive sampling Using Smart-PLS bootstrapping
			Proximal similarity	Heterogenous population, tested at different times
	Reliability	Stability	Test - re-test	n/a
		Internal consistency	Homogeneity	Cronbach's alpha, CR
		Equivalence	Alternative forms	Face-to-face and online questionnaire

6.3 Limitations

As in the case of all research, this study has limitations. First, owing to the complexity and broadness of the factors affecting the prosumer role, covering the entire research framework thoroughly in one dissertation was impossible. Hence, the articles represent a mere snapshot of the entire prosumer phenomenon even within the research framework. With the absence of a holistic view of energy prosumerism, I decided to approach the topic by placing the prosumer at the center of the inquiry and keeping the big picture in mind. The limited amount of earlier research on energy prosumers required a novel research approach that was explorative in nature to be developed. During the research, I wrote in total 16 articles as the first author and co-authored several more. Hence, the selection of articles for this dissertation limited the results and its contributions. However, the findings presented here as well as those left out of the scope of this dissertation contribute to the overall understanding of the prosumer role in the energy system and pave the way for many other research opportunities on this topic.

Second, due to the already broad topic, I decided to keep my focus on energy prosumers rather than prosumers in general. It would have been highly beneficial to be able to elaborate more on the prosumer related theories and experiences from other industries and extend the discussion also to allow the learnings from these industries shape the view of the energy prosumer more. This is definitely a topic that could be implemented in future research.

Third, the data collection in the consumer survey (N = 197) had limitations. The data were collected in the early phase of the research in five countries. At the time of the research design and data collection, both time and resources were limited. Hence, the small sample size of the quantitative data is clearly one of the limitations of this research. The Smart-PLS tool helped in managing the small sample size problem at least to some extent owing to its bootstrapping feature that allows the simulation of the data sample as a much larger sample (Hair et al. 2014). Some sample bias is also possible owing the need to include prosumers in the study. Furthermore, although the questionnaire covered several topics around the RQs, it had its limitations.

Fourth, while suited to study a novel topic that is not well-understood, exploratory research does not offer final and conclusive answers to existing problems. Likewise, typical to explorative research, the sample size of the consumer survey is rather small, which constrains the generalizability of the results. This is arguably a common problem to research in developing research fields, which is important to consider. The problem with generalizability also applies to the articles I, II, and III that were conducted based on the qualitative approach, wherein generalizability is often a challenge.

6.4 Future research avenues

The research scope of this study was broad; hence, the results presented in this dissertation can only cover some parts of the research gaps identified in the beginning. While the depth and breadth of prosumer research has increased during the time I have been working on this dissertation, considerable future research opportunities are still available. As discussed in the Introduction chapter 1, the sustainability transition research agenda (Köhler et al. 2019) includes multiple themes that could benefit from the prosumer-focused research. This dissertation attempted to contribute to some of these to paint a more holistic picture of energy prosumers as part of the sustainability transition. However, the picture is still far from complete.

First, a particularly interesting research topic is prosumer energy communities and how they fit into the energy system, markets, and the entire transition. There are multiple potential themes to explore concerning this topic. For example, Articles III, IV, and V shed some light on prosumers as innovators. However, understanding the energy communities' role in grassroots innovations is a topic that can benefit from more research (Hossain 2016; Klein and Coffey 2016; Köhler et al. 2019). Furthermore, building of the regulative frameworks for energy communities and their participation in the energy markets has just begun (Järventausta et al. forthcoming; Mengelkamp et al. 2017) and this work needs to continue.

Second, a deeper understanding of prosumer enablers and activities will benefit from further research. For example, more systemic activities such as those related to V2G integration to the power system combined with other prosumer activities offer opportunities for research. With the enablers for energy prosumers falling in place, more consumers will evolve into prosumers, which means that there will be more DG based on RESs in the energy system. Considerable research has been conducted for understanding the effects of increased variable generation on the energy system. When RES become a significant part of the system, the focus can be shifted toward the integration of DER into the system and then ensuring that these are efficiently managed. Therefore, the focus of future research could start moving to the next level: integration and efficient use of prosumer resources, as suggested in Article VI.

Third, to date, research on novel prosumer-centric business models and market mechanisms is scarce. For example, in terms of the energy prosumer activities, DR will be technically resolved by advanced metering, automation, and remote management. However, incentivizing consumer and prosumer participation is not well-understood and requires more studies and experiments (Paterakis et al. 2017). Furthermore, the V2G integration of EVs requires better understanding of the business models and roles of actors (Sovacool et al. 2017). Likewise, energy sales and trading, especially in virtual energy communities and P2P, is a topic on which research is still limited (Brilliantova and Thurner 2019; Kotilainen, Valta, et al. 2019; Lüth et al. 2018).

Fourth, a repetitive consumer study targeted at a larger population could be conducted as a confirmatory measure in the future. As the prosumer base has grown in many markets since the data collection, it would also be interesting to see if the results would be different: for example, concerning the difference between consumers and prosumers, as discussed in the appended Articles III, IV, and V.

Finally, understanding the optimal policy mixes to steer the sustainability transitions calls for more research (Köhler et al. 2019; Rogge and Reichardt 2016). Continuing the research started in Article VI would further deepen the understanding of the holistic policy approach concerning different actors in the energy system. Such research could bring a more fact-based approach to the policy setting and potentially increase the understanding of politicians regarding the implications of decision-making

7 REFERENCES

Adner, R. (2006). Match Your Innovation Strategy Innovation to YourEcosystem. *Harvard Business Review*, *84*(4), 98–107.

Adner, R. (2017). Ecosystem as Structure: An Actionable Construct for Strategy. *Journal of Management*, *43*(1), 39–58.

Agarwal, R., & Karahanna, E. (2000). Time flies when you're having fun: Cognitive absorption and beliefs about information technology usage. *MIS quarterly*, *24*(4), 665–694.

Ahola, J. (2019). *IEA PVPS - National Survey Report of PV Power Applications in Finland 2018*. Ursen, Switzerland: IEA.

Aiginger, K. (2007). Industrial policy: A dying breed or a re-emerging phoenix. *Journal of Industry, Competition and Trade*, *7*(3–4), 297–323.

Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. In J. Beckman & J. Kuhl (Eds.), *Action-control: From cognition to behavior.* (pp. 11–39). Heidelberg: Springer.

Akehurst, G., Afonso, C., & Martins Concalves, H. (2012). Re-examining green purchase behaviour and the green consumer profile: new evidences. *Management Decision*, *50*(5), 972–988.

Alam, S. S., Nik Hashim, N. H., Rashid, M., Omar, N. A., Ahsan, N., & Ismail, M. D. (2014). Small-scale households renewable energy usage intention: Theoretical development and empirical settings. *Renewable Energy*, *68*, 255–263.

Allcott, H., & Mullainathan, S. (2010). Behavioral and Energy Policy. *Science*, *327*(5970), 1204–1205.

Amabile, T. M. (1996). *Creativity in context: Update to the social psychology of creativity*. Boulder: Westview Press.

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., Mccallum, P., et al. (2019). Blockchain technology in the energy sector : A systematic review of challenges and opportunities. *Renewable and Sustainable Energy Reviews*, *100*, 143–174.

Annala, S., Viljainen, S., Tuunanen, J., & Honkapuro, S. (2014). Does Knowledge Contribute to the Acceptance of Demand Response ? *Journal of Sustainable Development of Energy, Water and Environment Systems*, *1*(2), 51–60.

Aquilani, B., Silvestri, C., Ioppolo, G., & Ruggieri, A. (2018). The challenging transition to bio-economies: Towards a new framework integrating corporate sustainability and value co-creation. *Journal of Cleaner Production*, *172*, 4001–4009.

Astarloa, B., Kaakeh, A., Lombardi, M., & Scalise, J. (2017). *The Future of Electricity: New Technologies Transforming the Grid Edge. World Economic Forum*. Geneva.

Balcombe, P., Rigby, D., & Azapagic, A. (2013). Motivations and barriers associated with adopting microgeneration energy technologies in the UK. *Renewable and Sustainable Energy Reviews*, *22*, 655–666.

Barbour, E., & González, M. C. (2018). Projecting battery adoption in the prosumer era. *Applied Energy*, *215*, 356–370.

Barney, J., & Felin, T. (2013). What are microfoundations? *Academy of management perspectives*, *27*(2), 138–155.

Barriball, K. L., & While, A. (1994). Collecting data using a semi-structured interview: a discussion paper. *Journal of Advanced Nursing - Institutional subscription*, *19*(2), 328–335.

Bartl, M., Jawecki, G., & Wiengandt, P. (2010). Co-creation in new product development: conceptual framework and application in the automotive industry. In *Conference Proceedings R&D Management Conference–Information, Imagination and Intelligence, Manchester. Vol 9.*

Baumgartner, F. R., & Jones, B. D. (2010). *Agendas and instability in American politics* (Second.). Chicago: University of Chicago Press.

Beland, D. (2007). Ideas and Institutional Change in Social Security : Conversion , Layering , and Policy Drift. *Social science quarterly*, *88*(1), 20–38.

Bellekom, S., Arentsen, M., Gorkum, K. Van, & van Gorkum, K. (2016). Prosumption and the distribution and supply of electricity. *Energy, Sustainability and Society*, *6*(1), 1–17.

Benders, R. M. J., Kok, R., Moll, H., Wiersma, G., & Noorman, K. J. (2006). New approaches for household energy conservation. In search of personal household energy budgets and energy reduction options. *Energy Policy*, *34*(18), 3612–3622.

Bergek, A., Hekkert, M. P., Jacobsson, S., Markard, J., Sandén, B., & Truffer, B. (2015). Technological Innovation Systems in contexts: conceptualizing contextual strucutres and interactions dynamics. *Environmental Innovation and Societal Transitions*, *Manuscript*(16), 51–64.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, *37*(3), 407–429.

Bergvall-Kåreborn, B., Ihlström, C., Ståhlbröst, A., & Svensson, J. (2009). A Milieu for Innovation – Defining Living Labs. *In ISPIM Innovation Symposium: 06/12/2009-09/12/2009.*.

Berlyne, D. E. (1966). Curiosity and exploration. *Science*, *153*(731), 25–33.

Bhatti, H. I., Hakkarainen, N., Huotari, H., & Mutikainen, T. (2018). *Energy service for electricity prosumers*. Espoo: Aalto University.

Bigerna, S., Bollino, C. A., & Micheli, S. (2016). Socio-economic acceptability for smart grid development–a comprehensive review. *Journal of Cleaner Production*, *131*, 399–409.

Blättel-Mink, B. (2014). Active consumership as a driver towards sustainability? *Gaia*, *23*, 158–165.

Blume, S. W. (2007). *Electric system basics for the non-electrical professional*. Hoboken, New Jersey: John Wiley & Sons.

Bollinger, B., & Gillingham, K. (2012). Peer effects in the diffusion of solar photovoltaic panels. *Marketing Science*, *31*(6), 900–912.

Boudreau, K. J., & Lakhani, Karim, R. (2013). Using the Crowd asan Innovation Partner. *Harvard Business Review*, *91*(4), 60–69.

Brandoni, C., Arteconi, A., Ciriachi, G., & Polonara, F. (2014). Assessing the impact of micro-generation technologies on local sustainability. *Energy Conversion and Management*, *87*, 1281–1290.

Brilliantova, V., & Thurner, T. W. (2019). Blockchain and the future of energy. *Technology in Society*, *57*, 38–45.

Briscoe, G. (2010). Complex adaptive digital ecosystems. *Proceedings of the International Conference on Management of Emergent Digital EcoSystems, 2010.*

Broman Toft, M., Schuitema, G., & Thøgersen, J. (2014). Responsible technology acceptance: Model development and application to consumer acceptance of Smart Grid technology. *Applied Energy*, *134*, 392–400.

Brown, R. B. (2006). *Doing Your Dissertation in Business and Management: The Reality of Research and Writing.* Padstow: Sage Publications.

Brunisholz, M. (2019). *IEA PVPS 2019 snapshot of global PV markets.* St.Ursen: IEA.

Bürer, M. J., & Wüstenhagen, R. (2009). Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international cleantech investors. *Energy Policy*, *37*(12), 4997–5006.

Burns, A. C., & Bush, R. F. (2006). Marketing Research. Upper Saddle River, (N.J.): Pearson/Prentice Hall.

Camek, A., Holzl, F., & Bytschkow, D. (2013). Providing security to a smart grid prosumer system based on a service oriented architecture in an office environment. In *2013 IEEE PES Innovative Smart Grid Technologies Conference, ISGT 2013*.

Campbell, D. T. (1986). Relabeling internal and external validity for applied social scientists. *New Directions for Program Evaluation*, *31*, 67–77.

Campoccia, A., Dusonchet, L., Telaretti, E., & Zizzo, G. (2014). An analysis of feed'in tariffs for solar PV in six representative countries of the European Union. *Solar Energy*, *107*(2014), 530–542.

Cappers, P., Goldman, C., & Kathan, D. (2010). Demand response in U.S. electricity markets: Empirical evidence. *Energy*, *35*(4), 1526–1535.

Carayannis, E. G., Barth, T. D., & Campbell, D. F. (2012). The Quintuple Helix innovation model: global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*, *1*(1), 2.

Carlsson, B., & Stankiewicz, R. (1991). On the nature, function and composition of technological systems. *Evolutionary economics*, *1*, 93–118.

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications : Current status , classification and open issues. *Telematics and Informatics*, *36*, 55–81.

Chaim, A., Sprei, F., Samaras, C., & Sean, Z. (2016). Effectiveness of incentives on electric vehicle adoption in Norway. *Transportation Research Part D*, *46*, 56–68.

Chang, E., & West, M. (2006). Digital ecosystems a next generation of the collaborative environment. In *8th International Conference on Information Integration and Web-based Applications & Services (iiWAS2006), Yogyakarta, Indonesia* (pp. 3–23).

Chau, P. Y. K., & Hu, P. J. (2002). Examining a model of information technology acceptance by individual professionals: An exploratory study. *Journal of Management Information Systems*, *18*(4), 191–229.

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. *Energy Research and Social Science*, *37*, 175–190.

Chesbrough, H. W. (2003). *Open Innovation: The new imperative for creating and profiting from technology.* Boston: Harvard Business Press.

Chesbrough, H. W., & Appleyard, M. M. (2007). Open Innovation and Strategy. *California Management Review*, *50*(1), 57–76.

Child, M., Kemfert, C., Bogdanov, D., & Breyer, C. (2019). Flexible electricity generation, grid exchange and storage for the transition to a 100% renewable energy system in Europe. *Renewable Energy*, *139*, 80–101.

Chin, J., & Lin, S. C. (2016). A behavioral model of managerial perspectives regarding technology acceptance in building energy management systems. *Sustainability (Switzerland)*, *8*(7), 641.

CIA. (2016). Country Age Structure.

Clark, C. F., Kotchen, M. J., & Moore, M. R. (2003). Internal and external influences on pro-environmental behavior: Participation in a green electricity program. *Journal of Environmental Psychology*, *23*(3), 237–246.

Cloutier, G., Papin, M., & Bizier, C. (2018). Do-it-yourself (DIY) adaptation: Civic initiatives as drivers to address climate change at the urban scale. *Cities*, *74*, 284–291.

Cochran, C. L., & Malone, E. F. (1999). *Public policy: Perspectives and choices* (2nd ed.). New York, NY: McGraw-Hill College.

Cooper, R. G. (2014). What's Next? After Stage-Gate. *Research-Technology Management*, *57*(1), 20–31.

Courtenay-Hall, P., & Rogers, L. (2002). Gaps in Mind: Problems in environmental knowledge-behaviour modelling research. *Environmental Education Research*, *8*(3), 283–297.

Craft, J., & Howlett, M. (2012). Policy formulation, governance shifts and policy influence: Location and content in policy advisory systems. *Journal of Public Policy*, *32*(2), 79–98.

Creswell, J. W., & Plano Clark, V. L. (2017). *Designing and conducting mixed methods research*. Thousand Oaks, California ; London, United Kingdom ; New Delhi, India ; Singapore: Sage Publications.

Davis, F. D. (1985). *A technology acceptance model for empirically testing new end-user information systems: Theory and results. Dissertation.* Massachusetts Institute of Technology.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, *13*(3), 319–334.

Davis, F. D., Baggozzi, R. P., & Warshaw, P. R. (1992). Extrinsic and intrinsic motivation to use computers in the workplace. *Journal of Applied Social Psychology*, *22*, 1111–1132.

Dedehayir, O., Mäkinen, S. J., & Roland Ortt, J. (2018). Roles during innovation ecosystem genesis: A literature review. *Technological Forecasting and Social Change*, *136*(November), 18–29.

Dehler, J., Keles, D., Telsnig, T., Fleischer, B., Baumann, M., Fraboulet, D., et al. (2017). Self-Consumption of Electricity from Renewable Sources. In *Europe's Energy Transition: Insights for Policy Making* (pp. 225–236). New York, NY: Academic Press.

Dewald, U., & Truffer, B. (2011). Market formation in technological innovation systems-diffusion of photovoltaic applications in Germany. *Industry and Innovation*, *18*(3), 285–300.

Dewald, U., & Truffer, B. (2012). The Local Sources of Market Formation: Explaining Regional Growth Differentials in German Photovoltaic Markets. *European Planning Studies*, *20*(3), 397–420.

Dosi, G. (1982). Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change. *Research Policy*, *11*(3), 147–162.

Doyle, L., Brady, A., Doyle, L., Brady, A., & Byrne, G. (2009). An overview of mixed methods research. *Journal of Research in Nursing*, *14*(2), 175–185.

Dronkers, B., Jeyakumar, B., Switzer, J., Vaughan-Morris, G. (, & McNaught, C. (2016). *Cost and financing aspects of community renewable energy projects. IEA-Renewable Energy Technology Deployment (REDT)* (Vol. 1).

Eid, C., Reneses Guillén, J., Frías Marín, P., & Hakvoort, R. (2014). The economic effect of electricity net-metering with solar PV: Consequences for network cost recovery, cross subsidies and policy objectives. *Energy Policy*, *75*(December), 244–254.

Eriksson, P., & Kovalainen, A. (2008). *Qualitative methods in business research*. London: Sage Publications.

Erlinghagen, S., & Markard, J. (2012). Smart grids and the transformation of the electricity sector: ICT firms as potential catalysts for sectoral change. *Energy Policy*, *51*, 895–906.

European commission. (2016). Proposal for a Directive of the European Parliament and of the Council on Common Rules for the Internal Market in Electricity' (Proposal for the Amendment of the Electricity Directive). Bruxelles, Belgium: European Commission.

European Commission. (2009). Third Energy Package. https://ec.europa.eu/energy/en/topics/markets-and-consumers/market-legislation/third-energy-package. Accessed 1 December 2019

European Commission. (2017). *Study on "Residential Prosumers in the European Energy Union."* European Commission, Bruxelles.

Feilzer, M. Y. (2010). Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm. *Journal of Mixed Methods Research*, *4*(1), 6–16.

Feller, J., & Fitzgerald, B. (2000). A framework analysis of the open source software development paradigm. In *Proceedings of the twenty first international conference on information systems.* (pp. 58–69). Association for Information Systems (AIS).

Figenbaum, E. (2017). Perspectives on Norway's supercharged electric vehicle policy. *Environmental Innovation and Societal Transitions*, *25*(December), 14–34.

FinSolar. (2019). FinSolar aurinkoenergiatietoa. https://finsolar.net. Accessed 1 December 2019

Fishbein, M., & Ajzen, I. (1975). *Belief, Attitude, Intention, and Behaviour: An Introduction to Theory and Research.* Reading, MA: Addision-Wesley.

Fisher, F., Miller, G. J., & Mara, S. (Eds.). (2006). *Handbook of public policy. Handbook of Public Policy.* Boca Raton, FL: CRC Press, Taylor & Francis Group.

Flaute, M., Großmann, A., Lutz, C., & Nieters, A. (2017). Macroeconomic effects of prosumer households in Germany. *International Journal of Energy Economics and Policy*, *7*(1), 146–155.

Fouquet, R. (2016). Path dependence in energy systems and economic development. *Nature Energy*, *1*(8), 16098.

Fox, S. (2014). Third Wave Do-It-Yourself (DIY): Potential for prosumption, innovation, and entrepreneurship by local populations in regions without industrial manufacturing infrastructure. *Technology in Society*, *39*(November), 18–30.

Foxon, T. J. (2002). *Technological and institutional ' lock-in ' as a barrier to sustainable innovation. Imperial College Centre for Policy and Technology Working Paper*. London.

Foxon, T. J., & Pearson, P. (2008). Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime. *Journal of Cleaner Production*, *16*(1), 148–161.

Frederiks, E. R., Stenner, K., & Hobman, E. V. (2015). Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable and Sustainable Energy Reviews*, *41*, 1385–1394.

Füller, J. (2010). Refining Virtual Co-Creation from a Consumer Perspective. *California Management Review*, *52*(2), 98–122

Gallo, A. B., Simões-Moreira, J. R., Costa, H. K. M., Santos, M. M., & Moutinho dos Santos, E. (2016). Energy storage in the energy transition context: A technology review. *Renewable and Sustainable Energy Reviews*, *65*, 800–822.

Gangale, F., Mengolini, A., & Onyeji, I. (2013). Consumer engagement: An insight from smart grid projects in Europe. *Energy Policy*, *60*, 621–628.

Gautier, A., Jacqmin, J., & Poudou, J.-C. (2018). The prosumers and the grid. *Journal of Regulatory Economics*, *53*(1), 100–126.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*, 1257–1274.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, *1*(1), 24–40.

Geels, F. W. (2012). A socio-technical analysis of low-carbon transitions : introducing the multi-level perspective into transport studies. *Journal of Transport Geography*, *24*(September), 471–482.

Geels, F. W. (2014). Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. *Theory, Culture & Society*, *31*(5), 21–40.

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417.

Geels, F. W., Turnheim, B., Aquith, M., Kern, F., & Kivimaa, P. (2019). *Sustainability transitions : policy and practice* (No. 09/2019). Luxenbourg: European Environment Agency (EEA).

Gensollen, N., Gauthier, V., Becker, M., & Marot, M. (2018). Stability and performance of coalitions of prosumers through diversification in the smart grid. *IEEE Transactions on Smart Grid*, *9*(2), 963–970.

Gensollen, N., Gauthier, V., Marot, M., & Becker, M. (2016). Submodular optimization for control of prosumer networks. In *2016 IEEE International Conference on Smart Grid Communications, SmartGridComm 2016* (pp. 180–185).

Giddings, B., Hopwood, B., & O'Brien, G. (2002). Environment, Economy and Society: Fitting Them Together Into Sustainable Development. *Wiley InterScience*, *10*, 187–196.

Granier, B., & Kudo, H. (2016). How are citizens involved in smart cities? Analysing citizen participation in Japanese "smart Communities." *Information Polity*, *21*(1), 61–76.

Grubb, M. (2004). Technology innovation and climate change - A overview of issues and options. *Keio Economic Studies*, *41*(2), 103–132.

Gunningham, N. (2013). Regulation, Economic Instruments, and Sustainable Energy. In *The Handbook of Global Energy Policy* (pp. 305–321). New York, NY: John Wiley & Sons:

Ha, S., & Stoel, L. (2009). Consumer e-shopping acceptance: Antecedents in a technology acceptance model. *Journal of Business Research*, *62*(5), 565–571.

Hacklin, F., Marxt, C., & Fahmi, F. (2010). An Evolutionary Perspective on Convergence: Including a Stage Model of Inter-Industry Innovation. *International Journal of Technology*, *49*(1–3), 220–249.

Haider, H. T., See, O. H., & Elmenreich, W. (2016a). A review of residential demand response of smart grid. *Renewable and Sustainable Energy Reviews*, *59*, 166–178.

Haider, H. T., See, O. H., & Elmenreich, W. (2016b). Residential demand response scheme based on adaptive consumption level pricing. *Energy*, *113*, 301–308.

Hair, J. F. J., Hult, G. T. M., Ringle, C., & Sarstedt, M. (2016). *A primer on partial least squares structural equation modeling (PLS-SEM)*. London, U.K.: Sage Publications.

Hair, J. F. J., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed a silver bullet. Journal of Marketing theory and Practice. *Journal of Marketing theory and Practice*, *19*(2), 139–152.

Hair, J. F. J., Sarstedt, M., Hopkins, L., & G. Kuppelwieser, V. (2014). Partial least squares structural equation modeling (PLS-SEM). *European Business Review*, *26*(2), 106–121.

Haukkala, T. (2019). *The wicked problem of a low carbon energy transition. Structure, agency and framing in the multi-actor process of solar PV deployment in Finland* (No. 65/2019). Aalto University publication series. Doctoral dissertations., Helsinki.

Head, B. W., & Alford, J. (2015). Wicked Problems: Implications for Public Policy and Management. *Administration and Society*, *47*(6), 711–739.

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence-Based Nursing*, *18*(3), 66–67.

Heiskanen, E., Laakso, S., Matschoss, K., Backhaus, J., Goggins, G., & Vadovics, E. (2018). Designing Real-World Laboratories for the Reduction of Residential Energy Use. *GAIA-Ecological Perspectives for Science and Society*, *27*(1), 60–67.

Heiskanen, E., & Lovio, R. (2010). User − Producer Interaction in Housing Energy Innovations. *Journal of industrial ecology*, *14*(1), 91–102.

Heiskanen, E., & Matschoss, K. (2011). Exploring Emerging Customer Needs for Smart Grid Applications. In *2nd IEEE PES Innovative Smart Grid Technologies Conference* (pp. 1–7).

Heiskanen, E., & Matschoss, K. (2016). Consumers as innovators in the electricity sector? Consumer perceptions on smart grid services. *International Journal of Consumer Studies*, 40(6), 665-674

Heiskanen, E., & Matschoss, K. (2017). Understanding the uneven diffusion of building-scale renewable energy systems: A review of household, local and country level factors in diverse European countries. *Renewable and Sustainable Energy Reviews*, *75*, 580–591.

Hertig, Y., & Teufel, S. (2016). Prosumer cooperation behavior: Implications for prosumer community design. *Journal of Electronic Science and Technology*, *14*(4), 298–310.

Hillman, K., Nilsson, M., Rickne, A., & Magnusson, T. (2011). Fostering sustainable technologies: a framework for analysing the governance of innovation systems. *Science and Public Policy*, *38*(5), 403–415.

Honkapuro, S., Haapaniemi, J., Haakana, J., Lassila, J., Belonogova, N., Partanen, J., et al. (2017). Development options for distribution tariff structures in Finland. *International Conference on the European Energy Market, EEM.*

Hossain, M. (2016). Grassroots innovation: A systematic review of two decades of research. *Journal of Cleaner Production*, *137*, 973–981.

Howe, J. (2006). The Rise of Crowdsourcing. *Wired Magazine*, *14*(06), 1–5.

Howlett, M., & Ramesh, M. (1995). *Studying Public Policy: Policy Cycles and Policy Subsystems*. (M. Howlett & M. Ramesh, Eds.). Canada: Oxford university press.

Howlett, M., & Ramesh, M. (2003). *Studying Public Policy: Policy cycles and policy subsystems*. (M. Howlett & M. Ramesh, Eds.). Toronto: Oxford University Press.

Huijts, N. M. A., Molin, E. J. E., & Steg, L. (2012). Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. *Renewable and Sustainable Energy Reviews*, *16*(1), 525–531.

Huttunen, R. (2017). *Valtioneuvoston selonteko kansallisesta energia- ja ilmastostrategiasta vuoteen 2030. Työ- ja elinkeinoministeriön julkaisuja* (Vol. 4/2017).

Hyyrynen, M. (2013). *Ympäristön kannalta haitalliset tuet* (Vol. 13). Helsinki: Ympäristöministeriö.

Hyysalo, S., Johnson, M., & Juntunen, J. K. (2017). The diffusion of consumer innovation in sustainable energy technologies. Journal of Cleaner Production. *Journal of Cleaner Production*, *162*, 70–82.

Hyysalo, S., Juntunen, J. K., & Freeman, S. (2013). User innovation in sustainable home energy technologies. *Energy Policy*, *55*, 490–500.

IEA-RETD. (2014). *Residential Prosumers - Drivers and Policy Options (RE-Prosumers). Renewable Energy Technology Deployment.*

IEA. (2017). *Global EV Outlook 2017: Two million and counting.* Paris, France.

IEA. (2019). *Global EV Outlook 2019: Scaling-up the transition to electric mobility*. Paris, France.

IEA. (2018). *Nordic EV Outlook 2018: Insights from leaders in electric mobility*. Paris, France.

Inderberg, T. H. J., Tews, K., & Turner, B. (2016). *Power from the People ? Prosuming conditions for Germany , the UK and Norway* (No. 6/2016 FNI Report).

Inderberg, T. H. J., Tews, K., & Turner, B. (2018). Is there a Prosumer Pathway? Exploring household solar energy development in Germany, Norway, and the United Kingdom. *Energy Research and Social Science*, *42*, 258–269.

International Energy Agency (IEA). (2016). World Energy Outlook 2016. *International Energy Agency: Paris, France*, 28.

IPCC. (2018). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,.* (V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, et al., Eds.). IPCC.

IRENA. (2018). *Innovation priorities to transform the energy system. An overview for policy makers.* Abu Dhabi: International Renewable Energy Agency (IRENA).

IRENA. (2019). *Innovation landscape brief: Supergrids.* Abu Dhabi.

Iria, J. P., Soares, F. J., & Matos, M. A. (2018). Trading Small Prosumers Flexibility in the Energy and Tertiary Reserve Markets. *IEEE Transactions on Smart Grid*, *10*(3), 2371–2382.

Jacobsson, S., & Lauber, V. (n.d.). The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology, 1–35.

Jansson, J., Marell, A., & Nordlund, A. (2008). Green consumer behavior: determinants of curtailment and eco-innovation adoption. *Journal of Consumer Marketing*, *27*(6), 358–370. doi:10.1108/07363761011052396

Järventausta, P. (2015). Smart Grids with large scale implementation of Automatic Meter Reading - Experiences from Finland. In *the Handbook of Clean Energy Systems.* Chichester: John Wiley & Sons, Ltd.

Järventausta, P., Peltonen, L., Valta, J., Uski, S., & Aalto, P. (2020). Microgrids: Impact on development of sustainable electric energy systems. In P. G. Özuyar, P. J. Pace, U. Azeiteiro, L. Brandli, & T. Wall (Eds.), *UN sustainable development goals.* Berlin, Germany: Springer.

Järventausta, P., Verho, P., Partanen, J., & Kronman, D. (2011). Finnish Smart Grids - A migration from version one to the next generation. In *Proceedings of the 21st International Conference on Electricity Distribution, Frankfurt, Germany, 6-9 June.*

Johnstone, P., Stirling, A., & Sovacool, B. (2017). Policy mixes for incumbency : Exploring the destructive recreation of renewable energy , shale gas ' fracking , ' and nuclear power in the United Kingdom. *Energy Research & Social Science*, *33*, 147–162.

Juntunen, J. K. (2014). *Prosuming Energy – User Innovation and New Energy Communities in Renewable Micro-Generation.* Aalto University publication series. Doctoral dissertations., Helsinki.

Kahneman, D. (2003). Maps of Bounded Rationality: Psychology of Behavioral Economics. *American Economic Review*, *93*(5), 1449–1475.

Kalkbrenner, B. J., & Roosen, J. (2016). Citizens' willingness to participate in local renewable energy projects: The role of community and trust in Germany. *Energy Research and Social Science*, *13*, 60–70.

Kampman, B., Blommerde, J., & Afman, M. (2016). *The potential of energy citizens in the European Union The potential of energy citizens in the European Union*. Delft: CE Delft.

Karakaya, E., Hidalgo, A., & Nuur, C. (2015). Motivators for adoption of photovoltaic systems at grid parity: A case study from Southern Germany. *Renewable and Sustainable Energy Reviews*, *43*, 1090–1098.

Kavis, M. (2016). Investors Guide to IoT part 1 - Understanding the Ecosystem. *Forbes.* http://www.forbes.com/sites/mikekavis/2016/02/24/investors-guide-to-iot-part-1-understanding-the-ecosystem/#55b47bfb6cef. Accessed 1 December 2019

Kemp, R., & Rip, A. (1998). Technological change. *Human choice and climate change*, *2*(2), 327–399.

Kemp, Rene, Loorbach, D., & Jan, R. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development sustainable development. *International Journal of Sustainable Development & World Ecology*, *14*(1), 78–91.

Kemp, René, Rotmans, J., & Loorbach, D. (2007). Assessing the Dutch Energy Transition Policy: How Does it Deal with Dilemmas of Managing Transitions? *Journal of Environmental Policy & Planning*, *9*(3–4), 315–331.

Kennedy, E. H., Beckley, T. M., McFarlane, B. L., & Nadeau, S. (2009). Why we don't "walk the talk": Understanding the environmental values/behaviour gap in Canada. *Human Ecology Review*, *16*(2), 151–160.

Kern, F., & Rogge, K. S. (2016). The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? *Energy Research and Social Science*, *22*, 13–17.

Kern, F., & Smith, A. (2008). Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. *Energy Policy*, *36*(11), 4093–4103.

Kester, J., Noel, L., Zarazua de Rubens, G., & Sovacool, B. K. (2018). Policy mechanisms to accelerate electric vehicle adoption: A qualitative review from the Nordic region. *Renewable and Sustainable Energy Reviews*, *94*, 719–731.

Ketikidis, P., Dimitrovski, T., Lazuras, L., & Bath, P. a. (2012). Acceptance of health information technology in health professionals: An application of the revised technology acceptance model. *Health Informatics Journal*, *18*(2), 124–134.

Kiviluoma, J., Rinne, E., & Helistö, N. (2018). Comparison of flexibility options to improve the value of variable power generation. *International journal of sustainable energy*, *37*(8), 761–781.
Kivimaa, P., Boon, W., Hyysalo, S., & Klerkx, L. (2019). Towards a typology of intermediaries in sustainability transitions : A systematic review and a research agenda. *Research Policy*, *48*(4), 1062–1075.
Kivimaa, P., & Kern, F. (2016). Creative Destruction or Mere Niche Creation? Innovation Policy Mixes for Sustainability Transitions. *Research Policy*, *45*(1), 205–217.
Klein, S. J. W., & Coffey, S. (2016). Building a sustainable energy future , one community at a time. *Renewable and Sustainable Energy Reviews*, *60*, 867–880.
Klitkou, A., Bolwig, S., Hansen, T., & Wessberg, N. (2015). The role of lock-in mechanisms in transition processes: The case of energy for road transport. *Environmental Innovation and Societal Transitions*, *16*, 22–37.
Knox-Hayes, J. (2012). Negotiating climate legislation: Policy path dependence and coalition stabilization. *Regulation and Governance*, *6*(4), 545–567.
Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., et al. (2019). An agenda for sustainability transitions research : State of the art and future directions. *Environmental Innovation and Societal Transitions*, *31*, 1–32.
Kohtala, C. (2015). Addressing sustainability in research on distributed production: An integrated literature review. *Journal of Cleaner Production*, *106*, 654–668.
Kojo, M., Kotilainen, K., & Rautiainen, A. (2018). *Miten sähköautopolitiikalla edistetään joustavampaa sähköjärjestelmää ?* (No. 2/2018 EL-TRAN analyysi).
Kollmuss, A., & Agyeman, J. (2002). Mind the Gap : Why do people act environmentally and what are the barriers to pro- environmental behavior? *Environmental Education Research*, *8*(3), 239–260.
Korjonen-Kuusipuro, K., Hujala, M., Pätäri, S., Bergman, J. P., & Olkkonen, L. (2017). The emergence and diffusion of grassroots energy innovations: building an interdisciplinary approach. *Journal of Cleaner Production*, *140*, 1156–1164.
Kotilainen, K. (2018). Energy prosumers' role in accelerating sustainability - An empirical study in five European countries. *27-29International Conference on the European Energy Market, EEM, Lodz, Poland June 27-29, IEEE Xplore*, 1–5.
Kotilainen, K. (2019). Prosumer role in the sustainable energy system. In (W. Leal Filho, A. M. Azul, L. Brandli, P. G. Özuyar, & T. Wall, Eds.)*Encyclopedia of the UN Sustainable Development Goals: Affortable and Clean Energy*. Springer.
Kotilainen, K., Aalto, P., Valta, J., Rautiainen, A., Kojo, M., & Sovacool, B. K. (2019). From path dependence to policy mixes for Nordic electric mobility: Lessons for accelerating future transport transitions? *Policy Sciences*, *52*(4), 573–600.
Kotilainen, K., Haukkala, T., Aalto, P., Rautiainen, A., & Kojo, M. (2018). *Sähköautopolitiikat Pohjoismaissa – mitä keinoja Suomi voi hyödyntää ?* (No. 6/2016 EL-TRAN analyysi) (Vol. 2018).
Kotilainen, K., Jarventausta, P., & Aalto, P. (2016). Prosumer centric co-creation in Smart Grid innovation ecosystem. In *IEEE Innovative Smart Grid Technologies Conference (ISGT-Asia), Melbourne, Australia, November 28 - December 1, IEEE Xplore* (pp. 884–889). doi:10.1109/ISGT-Asia.2016.7796502
Kotilainen, K., Mäkinen, S. J., & Järventausta, P. (2016). Understanding prosumers' intrinsic and extrinsic motivations to become active participants in smart grid innovation

ecosystem. In *Proceedings of IEEE Innovative Smart Grid Technologies, Europe 2016 conference* (pp. 1–6).

Kotilainen, K., Makinen, S. J., Järventausta, P., Rautiainen, A., & Markkula, J. (2016). The role of residential prosumers initiating the energy innovation ecosystem to future flexible energy system. In *13th international Conference on the European Energy Market, EEM, Porto, Portugal, June 6-9, IEEE Xplore* (Vol. 2016-July, pp. 1–5).

Kotilainen, K., Mäkinen, S. J., & Valta, J. (2017). Sustainable Electric Vehicle – Prosumer Framework and Policy Mix. In *Innovative Smart Grid Technologies (ISGT Asia), 4-7 Dec, Auckland, New Zealand, IEEE Xplore* (pp. 1–6).

Kotilainen, K., Saari, U. A., Mäkinen, S. J., & Ringle, C. M. (2019). Exploring the microfoundations of end-user interests toward co-creating renewable energy technology innovations. *Journal of Cleaner Production*, 229, 203-212

Kotilainen, K., Sommarberg, M., Järventausta, P., & Aalto, P. (2016). Prosumer centric digital energy ecosystem framework. *Proceedings of the 8th International Conference on Management of Digital EcoSystems - MEDES, Biarritz, France, November 1-4, ACM Digital Library*, 47–51.

Kotilainen, K., Valta, J., Makinen, S. J., & Jarventausta, P. (2017). Understanding consumers ' renewable energy behaviour beyond " homo economicus ": An exploratory survey in four European countries. *International Conference on the European Energy Market, EEM, Dresden, Germany, June 6-9, IEEE Xplore.*

Kotilainen, K., Valta, J., Systä, K., Mäkinen, S. J., Järventausta, P., & Björkqvist, T. T. (2019). Exploring the Potential of Blockchain as an Enabler for Three Types of Energy Communities. In *16th International Conference on the European Energy Market (EEM). Ljubljana, Slovenia, September 18-20, IEEE Xplore* (pp. 1–6). IEEE.

Kotler, P. (1986a). The prosumer movement: a new challenge for marketers. *Advances in Consumer research*, *13*, 510–513.

Kotler, P. (1986b). Prosumers: A New Type of Consumer. *The Futurist*, *20*(5), 24–28.

Kraft, M. E., & Clary, B. B. (1991). Citizen Participation and the Nimby Syndrome : Public Response to Radioactive Waste Disposal. *The Western Political Quarterly*, *44*(2), 299–328.

Kristensson, P., Matthing, J., & Johansson, N. (1991). Key strategies for the successful involvement of customers in the co-creation of new technology-based services. *International Journal of Service Industry Management*, *2*(2), 49–65.

Kruger, C., Caiado, R. G. ., Franca, S. L. B., & Quelhas, O. L. G. (2018). A holistic model integrating value co-creation methodologies towards the sustainable development. *Journal of Cleaner Production*, *191*, 400–416.

Kubli, M., Loock, M., & Wüstenhagen, R. (2018). The flexible prosumer: Measuring the willingness to co-create distributed flexibility. *Energy Policy*, *114*(March), 540–548.

Langbroek, J. H. M., Franklin, J. P., & Susilo, Y. O. (2016). The effect of policy incentives on electric vehicle adoption. *Energy Policy*, *94*, 94–103.

Laukkanen, M., & Patala, S. (2014). Analysing barriers to sustainable business model innovations: Innovation systems approach. *International Journal of Innovation Management*, *18*(6), 1440010.

Laws, N. D., Epps, B. P., Peterson, S. O., Laser, M. S., & Wanjiru, G. K. (2017). On the utility death spiral and the impact of utility rate structures on the adoption of residential solar photovoltaics and energy storage. *Applied Energy*, *185*, 627–641.

Lee, S. M., Olson, D. L., & Trimi, S. (2012). Co-innovation: convergenomics, collaboration, and co-creation for organizational values. *Management Decision*, *50*(5), 817–831.
Leminen, S., Westerlund, M., & Nyström, A. (2012). Living Labs as Open-Innovation Networks. *Technology Innovation Management Review*, *2*(9), 6–11.
Leydesdorff, L. (2012). The Triple Helix, Quadruple Helix, ..., and an N-Tuple of Helices: Explanatory Models for Analyzing the Knowledge-Based Economy? *Journal of the Knowledge Economy*, *3*(1), 25–35.
Lieven, T. (2015). Policy measures to promote electric mobility - A global perspective. *Transportation Research Part A: Policy and Practice*, *82*, 78–93.
Lincoln, Y. S., & Egon G. Guba. (1979). Naturalistic Inquiry. *Improving Human Performance Quarterly*, *8*(4), 268–276.
Liu, N., Yu, X., Wang, C., Li, C., Ma, L., & Lei, J. (2017). Energy-Sharing Model with Price-Based Demand Response for Microgrids of Peer-to-Peer Prosumers. *IEEE Transactions on Power Systems*, *32*(5), 3569–3583.
Loorbach, D. (2007). Transition management. In *New mode of governance for sustainable development.* Utrecht: International Books.
Loorbach, D. (2010). Transition management for sustainable development: a prescriptive, complexity-based governance framework. *Governance*, *23*(1), 161–183.
Lovio, R., Mickwitz, P., & Heiskanen, E. (2011). Path dependence, path creation and creative destruction in the evolution of energy systems. In *The handbook of research on energy entrepreneurship* (pp. 274–304). Cheltenham, UK: Edward Elgar Publishing.
Lowry, P. B., Gaskin, J. E., Twyman, N. W., Hammer, B., & Roberts, T. L. (2013). Taking "Fun and Games" Seriously: Proposing the Hedonic-Motivation System Adoption Model (HMSAM). *Journal of the Association for Information Systems*, *14*(11), 617–671.
Lu, J., Yu, C., Liu, C., & Yao, J. E. (2003). Technology acceptance model for wireless Internet. *Internet Research*, *13*(3), 206–222.
Lüth, A., Zepter, J. M., Crespo del Granado, P., & Egging, R. (2018). Local electricity market designs for peer-to-peer trading: The role of battery flexibility. *Applied Energy*, *229*, 1233–1243.
Maack, J. N. (2001). Scenario analysis: a tool for task managers. *Social Development Papers: Social Analysis, Selected Tools and Techniques*, *36*(June), 62–87.
Magis, K. (2010). Community resilience: An indicator of social sustainability. *Society and Natural Resources*, *23*(5), 401–416.
Malamaki, K.-N. D., Konstantinidis, I., & Demoulias, C. S. (2017). Analytical evaluation of the annual load duration curve of domestic prosumers. In *IEEE Manchester PowerTech, Powertech, Manchester UK, June 18-22, IEEE*.
Mamounakis, I., Vergados, D. J., Makris, P., Varvarigos, E., & Doulamis, N. D. (2017). Renewable energy prosumers clustering towards target aggregated prosumption profiles based on recursive predictions. In *IEEE Manchester PowerTech, Powertech, Manchester UK, June 18-22, IEEE* (pp. 1–6).
Mamounakis, I., Vergados, D. J., Makris, P., Varvarigos, E., & Mavridis, T. (2015). A Virtual MicroGrid platform for the efficient orchestration of multiple energy prosumers. In *ACM International Conference Proceeding Series* (Vol. 01-03-Octo, pp. 191–196).
Marjamäki, R. (2019). Energiayhteisössä kuluttajista tulee myös tuottajia – Lempääläisellä yritysalueella itse tuotettua sähköä ohjataan älykkäästi. *Kuntalehti*. https://kuntalehti.fi/uutiset/energiayhteisossa-kuluttajista-tulee-myos-tuottajia-

lempaalaisella-yritysalueella-itse-tuotettua-sahkoa-ohjataan-alykkaasti/. Accessed 1 December 2019

Markard, J. (2017). Sustainability Transitions : Exploring the emerging research field and its contribution to management studies. In *The proceedings of 33rd EGOS Colloquium, Copenhagen, Denmark, July 5-8*.

Markard, J. (2018). The next phase of the energy transition and its implications for research and policy. *Nature Energy*, *3*(8), 628–633.

Markard, J., Hekkert, M., & Jacobsson, S. (2015). The technological innovation systems framework : Response to six criticisms. *Environmental Innovation and Societal Transitions*, *16*, 76–86.

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, *41*(6), 955–967.

Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy*, *37*(4), 596–615.

Markham, S. K., Ward, S. J., Aiman-Smith, L., & Kingon, A. I. (2010). The valley of death as context for role theory in product innovation. *Journal of Product Innovation Management*, *27*(3), 402–417.

Martín-Martínez, F., Sánchez-Miralles, A., & Rivier, M. (2016). Prosumers' optimal DER investments and DR usage for thermal and electrical loads in isolated microgrids. *Electric Power Systems Research*, *140*, 473–484.

Martiskainen, M., & Kivimaa, P. (2018). Creating innovative zero carbon homes in the United Kingdom — Intermediaries and champions in building projects. *Environmental Innovation and Societal Transitions*, *26*(November 2016), 15–31.

Masini, A., & Menichetti, E. (2013). Investment decisions in the renewable energy sector: An analysis of non-financial drivers. *Technological Forecasting and Social Change*, *80*(3), 510–524.

Masson, G., Orlandi, S., Petrick, K., Cassagne, V., Briano, J. I., Morandi, Maria, J. B., et al. (2014). PV Development As Prosumers : the Role and Challenges Associated To Producing and Self-Consuming Pv Electricity. In *4th International Workshop on Integration of Solar Power into Power Systems, Berlin, Germany, November 11-14*.

Matschoss, K., Kahma, N., & Heiskanen, E. (2015). Pioneering customers as change agents for new energy efficiency services—an empirical study in the Finnish electricity markets. *Energy Efficiency*, *8*(5), 827–843.

Maxwell, J. A. (2012). *A realist approach for qualitative research*. Thousand Oaks, California ; London, United Kingdom ; New Delhi, India ; Singapore: Sage Publications.

McCombs, M. E., & Shaw, D. L. (1993). The Evolution of Agenda‐Setting Research: Twenty‐Five Years in the Marketplace of Ideas. *Journal of Communication*, *43*(2), 58–67.

McDaniel, P., & McLaughlin, S. (2009). Security and privacy challenges in the Smart Grid. *IEEE Security & Privacy*, *7*(3), 75–77.

Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., & Weinhardt, C. (2018). Designing microgrid energy markets A case study : The Brooklyn Microgrid. *Applied Energy*, *210*, 870–880.

Metcalfe, R. (2013). Metcalfe's Law Revisited after 40 Years of Ethernet. *Computer*, *46*(12), 26–31.

Michels, A., & De Graaf, L. (2017). Examining Citizen Participation: Local Participatory Policy Making and Democracy. *Local goverment studies*, *36*(4), 477–491.

Miller, W., & Senadeera, M. (2017). Social transition from energy consumers to prosumers: Rethinking the purpose and functionality of eco-feedback technologies. *Sustainable Cities and Society*, *35*, 615–625.

Moore, G. A. (1991). *Crossing the Chasm*. New York: Harper Business Essentials.

Moore, J. (1996). *The Death of Competition - Leadership and Strategy in the Age of Business Ecosystems*. New York: Harper Business Essentials.

Moore, J. F. (1993). Predators and prey: A new ecology of competition. *Harvard Business Review*, *71*(3), 75–86.

Morstyn, T., Farrell, N., Darby, S. J., & McCulloch, M. D. (2018). Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants. *Nature Energy*, *3*(2), 94–101.

Müller, S., & Rode, J. (2013). The adoption of photovoltaic systems in Wiesbaden, Germany. *Economics of Innovation and New Technology*, *22*(5), 519–535.

Nachira, F. (2006). Digital Business Ecosystems Transition towards the knowledge-economy SMEs : a weakness or a potential for Europe ? SMEs in a Dynamic knowledge-based globally-networked economy - How to reach the critical mass of resources ? In *Sardegna Terra ICT June 2006* (pp. 1–9). Pula.

Nachira, F., Dini, P., & Nicolai, A. (2007). Network of Digital Ecosystems for Europe: Roots, Processes and Perspectives. European Commission, Bruxelles.

Nambisan, S. (2010). Virtual Customer Environments: IT-Enabled Customer Co-innovation and Value Co-creation. In *Information technology and product development - annals of information systems* (pp. 109–127). Boston, MA: Springer.

Naspetti, S., Mandolesi, S., Buysse, J., Latvala, T., Nicholas, P., Padel, S., et al. (2017). Determinants of the acceptance of sustainable production strategies among dairy farmers: Development and testing of a modified technology acceptance model. *Sustainability (Switzerland)*, *9*(10), 1–16.

Naus, J., Van Vliet, B. J. M., & Hendriksen, A. (2015). Households as change agents in a Dutch smart energy transition: On power, privacy and participation. *Energy Research and Social Science*, *9*, 125–136.

Negro, S. O., Alkemade, F., & Hekkert, M. P. (2012). Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable and Sustainable Energy Reviews*, *16*(6), 3836–3846.

Nesti, G. (2018). Co-production for innovation: the urban living lab experience experience. *Policy and Society*, *37*(3), 310–325.

Nidumolu, R., Prahalad, C. K., & Rangaswami, M. R. (2009). Why sustainability is now the key driver of innovation. *Harvard Business Review*, *87*(9), 57–64.

Nielsen, K. R., Reisch, L. A., & Thøgersen, J. (2016). Sustainable user innovation from a policy perspective: a systematic literature review. *Journal of Cleaner Production*, *133*, 65–77.

Nolan, S., & O'Malley, M. (2015). Challenges and barriers to demand response deployment and evaluation. *Applied Energy*, *152*, 1–10.

Nolden, C. (2019). Transaction Cost Analysis of Digital Innovation Governance in the UK Energy Market. Forthcoming (2019). *Journal of Energy Markets*, *Forthcoming*.

Noll, D., Dawes, C., & Rai, V. (2014). Solar community organizations and active peer effects in the adoption of residential PV. *Energy Policy*, *67*, 330–343.

Nyborg, S., & Ropke, I. (2013). Constructing users in the smart grid—insights from the Danish eFlex project. *Energy Efficiency*, *6*(4), 655–670.

Nygren, N. A., Kontio, P., Lyytimäki, J., Varho, V., & Tapio, P. (2015). Early adopters boosting the diffusion of sustainable small-scale energy solutions. *Renewable and Sustainable Energy Reviews*, *46*(June), 79–87.

OECD. (2001). *Sustainable development - critical issues*. Paris: OECD.

Ogawa, R. T., & Malen, B. (1991). Towards Rigor in Reviews of Multivocal Literatures : Applying the Exploratory Case. *Review of educational research*, *61*(3), 265–286.

Oh, D. S., Phillips, F., Park, S., & Lee, E. (2016). Innovation ecosystems: A critical examination. *Technovation*, *54*(August), 1–6.

Olinsky-Paul, T. (2019). *Energy storage is the new efficiency. Renewable energy world.* https://www.renewableenergyworld.com/2019/04/22/energy-storage-is-the-new-efficiency/#gref. Accessed 28 March 2020

Olkkonen, L., Korjonen-Kuusipuro, K., & Grönberg, I. (2017). Redefining a stakeholder relation: Finnish energy "prosumers" as co-producers. *Environmental Innovation and Societal Transitions*, *24*, 57–66.

Onwuegbuzie, A. J., & Johnson, R. B. (2006). The Validity Issue in Mixed Research. *Research in the schools*, *13*(1), 48–63.

Ornetzeder, M., & Rohracher, H. (2006). User-led innovations and participation processes: Lessons from sustainable energy technologies. *Energy Policy*, *34*(2 SPEC. ISS.), 138–150.

Ornetzeder, M., & Rohracher, H. (2013). Of solar collectors, wind power, and car sharing: Comparing and understanding successful cases of grassroots innovations. *Global Environmental Change*, *23*(5), 856–867.

Ossenbrink, J. (2017). How feed-in remuneration design shapes residential PV prosumer paradigms. *Energy Policy*, *108*(September), 239–255.

Ottesen, S. Ø., Svendby, C., & Tomasgard, A. (2013). Demand side operational flexibility - A holistic stochastic optimization model for flexible consumers and prosumers. In *IET Conference Publications, Stockholm, Sweden, June 10-13*.

Ottesen, S. Ø., Tomasgard, A., & Fleten, S.-E. (2016). Prosumer bidding and scheduling in electricity markets. *Energy*, *94*, 828–843.

Oughton, C., Landabaso, M., & Morgan, K. (2002). The regional innovation paradox: Innovation policy and industrial policy. *Journal of Technology Transfer*, *27*(1), 97–110.

Pallot, M., Trousse, B., Senach, B., & Scapin, D. (2010). Living Lab Research Landscape: From User Centred Design and User Experience towards User Cocreation. In *First European Summer School" Living Labs"* (Vol. August, pp. 19–25). Paris, France.

Palm, A. (2017). Peer effects in residential solar photovoltaics adoption—A mixed methods study of Swedish users. *Energy Research and Social Science*, *26*, 1–10.

Palm, J., & Tengvard, M. (2011). Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden. *Sustainability: Science, Practice & Policy*, *7*(1), 6–15. 1

Parag, Y., & Sovacool, B. K. (2016). Electricity market design for the prosumer era. *Nature Energy*, *1*(4), 16032.

Park, L. W., Lee, S., & Chang, H. (2018). A sustainable home energy prosumer-chain methodology with energy tags over the blockchain. *Sustainability (Switzerland)*, *10*(3).

Pasetti, M., Rinaldi, S., & Manerba, D. (2018). A virtual power plant architecture for the demand-side management of smart prosumers. *Applied Sciences (Switzerland)*, *8*(3).

Paterakis, N. G., Erdinç, O., & Catalão, J. P. S. (2017). An overview of Demand Response: Key-elements and international experience. *Renewable and Sustainable Energy Reviews*, *69*, 871–891.

Pegels, A., & Lütkenhorst, W. (2014). Is Germany's energy transition a case of successful green industrial policy? Contrasting wind and solar PV. *Energy Policy*, *74*(C), 522–534.

Pesch, U. (2015). Tracing Discursive Space: Agency and Change in Sustainability Transitions. *Technological Forecasting and Social Change*, *90*, 379–388.

Pickett-Baker, J., & Ozaki, R. (2008). Pro-environmental products: marketing influence on consumer purchase decision. *Journal of Consumer Marketing*, *25*(5), 281–293.

Pierson, P. (2000). Increasing Returns , Path Dependence , and the Study of Politics. *The American Political Science Review*, *94*(2), 251–267.

Piller, F., & Walcher, D. (2006). Toolkits for Idea Competitions: A Novel Method to Integrate Users in New Product Development. *R&D Management*, *36*(3), 307–318.

Pinto, R., Bessa, R. J., & Matos, M. A. (2017). Multi-period flexibility forecast for low voltage prosumers. *Energy*, *141*(December), 2251–2263.

Poortinga, W., Steg, L., & Vlek, C. (2004). Values, Environmental Concern, and Environmental Behavior A Study into Household Energy Use. *Environment and Behavior*, *36*(1), 70–93.

Porter, M. E. (2008). The five competitive forces that shape strategy. *Harward Business Review*, *86*(1), 25–40.

Prahalad, C. K., & Bettis, R. A. (1986). The Dominant Logic: a New Linkage Between Diversity and Performance. *Strategic Management Journal*, *7*(6), 485–501.

Prahalad, C. K., & Ramaswamy, V. (2004). Co-Creating Unique Value With Customers. *Strategy and Leadership*, *32*(3), 4–9.

Qiu, J., Zhao, J., Yang, H., & Dong, Z. Y. (2018). Optimal Scheduling for Prosumers in Coupled Transactive Power and Gas Systems. *IEEE Transactions on Power Systems*, *33*(2), 1970–1980.

Rai, V., Reeves, D. C., & Margolis, R. (2016). Overcoming barriers and uncertainties in the adoption of residential solar PV. *Renewable Energy*, *89*, 498–505.

Ramachandran, T., Costello, Z., Kingston, P., Grijalva, S., & Egerstedt, M. (2012). Distributed power allocation in prosumer networks. In *IFAC Proceedings Volumes 45.26 (IFAC-PapersOnline)* (pp. 156–161).

Ramírez, F. J., Honrubia-Escribano, A., Gómez-Lázaro, E., & Pham, D. T. (2017). Combining feed-in tariffs and net-metering schemes to balance development in adoption of photovoltaic energy: Comparative economic assessment and policy implications for European countries. *Energy Policy*, *102*(January), 440–452.

Rathnayaka, A. J. D. D., Potdar, V. M. V. M., & Kuruppu, S. J. S. J. (2011). An innovative approach to manage prosumers in Smart Grid. In *2011 World Congress on Sustainable Technologies (WCST), London, UK, November 7-10* (pp. 141–146).

Rathnayaka, A. J. D. D., Potdar, V. M., Dillon, T., Hussain, O., & Kuruppu, S. (2012). Analysis of energy behaviour profiles of prosumers. In *IEEE International Conference on Industrial Informatics (INDIN)* (pp. 236–241).

Reddy, S., & Painuly, J. P. (2004). Diffusion of renewable energy technologies-barriers and stakeholders' perspectives. *Renewable Energy*, *29*(9), 1431–1447.

Ringle, C. M., & Sarstedt, M. (2016). Gain more insight from your PLS-SEM results: The importance-performance map analysis. *Industrial Management & Data Systems*, *116*(9), 1865–1886.

Ritzer, G., & Jurgenson, N. (2010). Production, Consumption, Prosumption: The nature of capitalism in the age of the digital "prosumer." *Journal of Consumer Culture*, *10*(1), 13–36.

Rocha, A. D. F. R., Santos, I. C. dos, & Vieira, A. M. (2018). Semi open Innovation: an Approach to the Innovation Typology. *Future Studies Research Journal: Trends and Strategies*, *10*(1), 55–81.

Rogers, E. M. (1962). *Diffusion of Innovations* (1st ed.). New York, NY: Free Press of Glencoe.

Rogers, E. M. (1995). *Diffusion of Innovations* (4th ed.). New York, NY: Free Press of Glencoe.

Rogers, E. M. (2003). *Diffusion of Innovations.* (5th ed.). New York: Simon&Schuster.

Rogge, K. S., & Johnstone, P. (2017a). Energy Research & Social Science Exploring the role of phase-out policies for low-carbon energy transitions : The case of the German Energiewende. *Energy Research & Social Science*, *33*(October), 128–137.

Rogge, K. S., & Johnstone, P. (2017b). Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende. *Energy Research and Social Science*, *33*(October), 128–137.

Rogge, K. S., & Rechardt, K. (2013). *Towards a more comprehensive policy mix conceptualization for environmental technological change: a literature synthesis* (No. Working Paper Sustainability and Innovation S3/2013). Karlsruhe.

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions : An extended concept and framework for analysis. *Research Policy*, *45*(8), 1620–1635.

Rosen, C., & Madlener, R. (2016). Regulatory options for local reserve energy markets: Implications for prosumers, utilities, and other stakeholders. *Energy Journal*, *37*(Special Is), 39–50.

Rotmans, J, Kemp, R., & van Asselt, M. B. A. (2001). More evolution than revolution: transition management in public policy. *Foresight*, *3*(1), 1–17.

Rotmans, Jan, & Kemp, R. R. (2003). Managing Societal Transitions: Dilemmas and Uncertainties: The Dutch energy case study. *OECD Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers*. OECD.

Ruostetsaari, I. (2010). Changing regulation and governance of finnish energy policy making: New rules but old elites? *Review of Policy Research*, *27*(3), 273–297.

Ruostetsaari, I., Aalto, P., Kallioharju, K., Kojo, M., Rautiainen, A., & Toivanen, P. (2016). *Suomalaiset eivät lämpene sähköautoille – miten kiinnostus sytytetään?* (No. 6/2016 EL-TRAN analyysi).

Ruostetsaari, I., Kotilainen, K., Harsia, P., Heljo, J., Kallioharju, K., Kojo, M., et al. (2018). *Suomalaiset sähkön käyttäjinä ja tuottajina : valmius kysyntäjoustoon ja omakohtaiseen sähköntuotantoon* (No. 4/2018 EL-TRAN analyysi).

Ryan, R., & Deci, E. (2000). Self-determination theory and the facilitation of intrinsic motivation. *American Psychologist*, *55*(1), 68–78.

Ryan, R., Rigby, C., & Przybylski, A. (2006). The motivational pull of video games: A self-determination theory approach. *Motivation and Emotion*, *30*(4), 344–360.

Saele, H., & Grande, O. S. (2011). Demand response from household customers: Experiences from a pilot study in Norway. *IEEE Transactions on Smart Grid*, *2*(1), 90–97.

Sajn, N. (2016). *Electricity ' Prosumers '*. Brussels, Belgium: European Parliamentary Research Service (EPRS).

Sandoval, M., & Grijalva, S. (2016). Future grid business model innovation: A prosumer-based cost-benefit framework for valuation of Distributed Energy Resources. In *2015*

IEEE PES Innovative Smart Grid Technologies Latin America, ISGT LATAM 2015 (pp. 450–455).

Sarstedt, M., Ringle, C. M., & Hair, J. F. J. (2017). Partial Least Squares Structural Equation Modeling. In C. Homburg, M. Klarmann, & A. Vomberg (Eds.), *Handbook of Market Research*, Vol 267 (pp. 1–40). Springer.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for Business Students* (5th ed.). Pearson Education.

Scarpa, R., & Willis, K. (2010). Willingness-to-pay for renewable energy: Primary and discretionary choice of British households' for micro-generation technologies. *Energy Economics*, *32*(1), 129–136.

Schamela, M. (2018). *Global market oulook for solar power 2018-2022*. Brussels, Belgium: Solar Power Europe.

Schamela, M., Beauvais, A., Chevillard, N., Guillén Paredes, M., Heisz, M., & Rossi, R. (2019). *Global Market Outlook For Solar Power 2019 - 2023*. Brussels, Belgium: Solar Power Europe.

Schelly, C. (2014). Residential solar electricity adoption: What motivates, and what matters? A case study of early adopters. *Energy Research and Social Science*, *2*(June), 183–191.

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554.

Schot, J., Kanger, L., & Verbong, G. P. J. (2016). The roles of users in shaping transitions to new energy systems. *Nature Energy*, *1*(5), 16054.

Schumpeter, J. A. (1942). Creative Destruction. *Capitalism and the Process of Creative Destruction*, *825*(5), 82–85.

Schwartz, S. H. (1977). Normative Influences on Altruism. In L. Berkowitz (Ed.), *Advances in Experimental Social Psychology* (Vol. 10, pp. 221–279). Academic Press, New York.

Scrase, I., & Mackerron, G. (Eds.). (2009). *Energy for the Future: A New Agenda.* London: Palgrave Macmillan.

Seyfang, G., & Haxeltine, A. (2012). Growing grassroots innovations: Exploring the role of community-based initiatives in governing sustainable energy transitions. *Environment and Planning C: Government and Policy*, *30*(3), 381–400.

Sgouridis, S., & Csala, D. (2014). A framework for defining sustainable energy transitions: Principles, dynamics, and implications. *Sustainability (Switzerland)*, *6*(5), 2601–2622.

Shakeri, M., Shayestegan, M., Abunima, H., Reza, S. M. S., Akhtaruzzaman, M., Alamoud, A. R. M., et al. (2017). An intelligent system architecture in home energy management systems (HEMS) for efficient demand response in smart grid. *Energy and Buildings*, *138*, 154–164.

Sheeran, P., & Abraham, C. (2003). Mediator of moderators: temporal stability of intention and the intention-behavior relation. *Personality and Social Psychology Bulletin*, *29*(2), 205–215.

Shmueli, G., Ray, S., & Velasquez Estrada, J. M. (2016). The Elephant in the Room: Evaluating the Predictive Performance of PLS Models. 69(10): . *Journal of Business Research*, *69*(10), 4552–4564.

Simon, H. A. . (2011). A Behavioral Model of Rational Choice. *The Quarterly Journal of Economics*, *69*(1), 99–118.

Skjølsvold, T. M., Throndsen, W., Ryghaug, M., Fjellså, I. F., & Koksvik, G. H. (2018). Orchestrating households as collectives of participation in the distributed energy

transition: New empirical and conceptual insights. *Energy Research and Social Science*, *46*(December 2017), 252–261.
Smits, R., & Kuhlmann, S. (2004). The rise of systemic instruments in innovation policy. *International Journal of Foresight and Innovation Policy*, *1*(1–2), 4–32.
Sousa, T., Soares, T., Pinson, P., Moret, F., Baroche, T., & Sorin, E. (2019). Peer-to-peer and community-based markets: A comprehensive review. *Renewable and Sustainable Energy Reviews*, *104*, 367–378.
Sovacool, B. K., Axsen, J., & Kempton, W. (2017). The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda. *Annual Review of Environment and Resources*, *42*(1), 377–406.
Sovacool, B. K., & Blyth, P. L. (2015). Energy and environmental attitudes in the green state of Denmark: Implications for energy democracy, low carbon transitions, and energy literacy. *Environmental Science and Policy*, *54*(December), 304–315.
Sovacool, B. K., & Lakshmi Ratan, P. (2012). Conceptualizing the acceptance of wind and solar electricity. *Renewable and Sustainable Energy Reviews*, *16*(7), 5268–5279.
Spender, J.-C. (1989). *Industry Recipes, An Enquiry into Nature and Sources of Managerial Judgement.* Oxford: Basil Blackwell Ltd.
Statistics Finland. (2019). Greenhouse gas emissions increased, emission allocation exceeded. https://www.stat.fi/til/khki/2018/khki_2018_2019-05-23_tie_001_en.html. Accessed 1 December 2019
Stenner, K., Frederiks, E. R., Hobman, E. V., & Cook, S. (2017). Willingness to participate in direct load control: The role of consumer distrust. *Applied Energy*, *189*, 76–88.
Stern, P. C., Abel, T. D., Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., & Kalof, L. (1999). A Value-Belief-Norm Theory of Support for Social Movements : The Case of Environmentalism. *Human ecology review*, *6*(2), 81–97.
Strengers, Y. (2014). Smart energy in everyday life: Are you designing for resource man? *Interactions*, *21*(4), 24–31.
Surendran, P. (2012). Technology Acceptance Model : A Survey of Literature. *International Journal of Business and Social Research*, *2*(4), 175–178.
Szulecki, K. (2018). Conceptualizing energy democracy. *Environmental Politics*, *27*(1), 21–41.
Talmar, M., Walrave, B., Podoynitsyna, K. S., Holmström, J., & Romme, A. G. L. (2018). Mapping, analyzing and designing innovation ecosystems: The Ecosystem Pie Model. *Long Range Planning*, 101850.
Tapscott, D., & Williams, A. D. (2008). Wikinomics: How mass collaboration changes everything. New York: Penguin.
Tashakkori, A., & Teddlie, C. (2003). The past and future of mixed methods research: From data triangulation to mixed model designs. In *Handbook of mixed methods in social and behavioral research* (pp. 671–701). Thousand Oaks, California ; London, United Kingdom ; New Delhi, India ; Singapore: Sage Publications.
Tashakkori, A., & Teddlie, C. (2009). *Integrating qualitative and quantitative approaches to research. Handbook of Applied Social Research Methods*. Thousand Oaks, California ; London, United Kingdom ; New Delhi, India ; Singapore: Sage.
TEM. (2018). *Joustava ja asiakaskeskeinen sähköjärjestelmä - Älyverkkotyöryhmän loppuraportti* (No. 33/2018 Työ-ja elinkeinoministeriön julkaisuja).
Toffler, A. (1981). *The third wave*. (B. Williams & T. Tapscott, Eds.). New York: Bantam Books.

Toye, F., Seers, K., Allcock, N., Briggs, M., Carr, E., Andrews, J., & Barker, K. (2013). "Trying to pin down jelly" - Exploring intuitive processes in quality assessment for meta-ethnography. *BMC Medical Research Methodology*, *13*(1), 1–12.

Trochim, W. M., & Donnelly, J. P. (2001). *Research methods knowledge base (Vol. 2).* (2nd ed.). Cincinnati, OH: Atomic Dog Publishing.

Tsoutsos, T. D., & Stamboulis, Y. A. (2005). The sustainable diffusion of renewable energy technologies as an example of an innovation-focused policy. *Technovation*, *25*(7), 753–761.

Turner, R. H. (1990). Role change. *Annual review of sociology*, *16*(1), 87–110.

Turnheim, B., & Geels, F. W. (2012). Regime destabilisation as the flip side of energy transitions: lessons from the history of the British coal industry (1913–1997). *Energy Policy*, *50*, 35–49.

Uddin, K., Gough, R., Radcliffe, J., Marco, J., & Jennings, P. (2017). Techno-economic analysis of the viability of residential photovoltaic systems using lithium-ion batteries for energy storage in the United Kingdom. *Applied Energy*, *206*(July), 12–21.

Unruh, G. C., & Carrillo-Hermosilla, J. (2006). Globalizing carbon lock-in. *Energy Policy*, *34*(10), 1185–1197.

Unruh, G. G. (2000). Understanding carbon lock-in. *Energy policy*, *28*, 817–830.

Valles, M., Reneses, J., Cossent, R., & Frias, P. (2016). Regulatory and market barriers to the realization of demand response in electricity distribution networks: A European perspective. *Electric Power Systems Research*, *140*, 689–698.

Valta, J. (2017). *Policy pathways towards energy prosumer innovation ecosystem– cross-country comparison from Europe.* M.Sc. Thesis. Tampere University of Technology.

Valta, J., Mäkinen, S. J., Kotilainen, K., Rautiainen, A., & Järventausta, P. (2018). Comparison of Innovation Policies for Electric Vehicle Business Ecosystems. In *15th International Conference on the European Energy Market (EEM). IEEE* (pp. 1–5).

Van Der Schoor, T., & Scholtens, B. (2015). Power to the people: Local community initiatives and the transition to sustainable energy. *Renewable and Sustainable Energy Reviews*, *43*, 666–675.

Vanthournout, K., Dupont, B., Foubert, W., Stuckens, C., & Claessens, S. (2015). An automated residential demand response pilot experiment, based on day-ahead dynamic pricing. *Applied Energy*, *155*, 195–203.

Vedung, E. (1998). *Policy instruments: typologies and theories. Carrots, Sticks and Sermons: Policy Instruments and Their Evaluation.* New Brunswick: Transaction publishers.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2017). User acceptance of information technology: toward a unified view. *MIS Quarterly*, *27*(3), 425–478.

Verbong, G. P. J., & Geels, F. W. (2010). Exploring sustainability transitions in the electricity sector with socio-technical pathways. *Technological Forecasting and Social Change*, *77*(8), 1214–1221.

von Hippel, E. (1986). Lead users: a source of novel product concepts. *Management science*, *32*(7), 791–805.

von Hippel, E. (2005). Democratizing innovation: The evolving phenomenon of user innovation. *Journal für Betriebswirtschaft*, *55*(1), 63–78.

Wainstein, M. E., Dargaville, R., & Bumpus, A. (2017). Social virtual energy networks: Exploring innovative business models of prosumer aggregation with virtual power plants. In *2017 IEEE Power and Energy Society Innovative Smart Grid Technologies Conference, ISGT 2017*.

Wallsten, A., & Galis, V. (2019). The discreet charm of activeness: the vain construction of efficient smart grid users. *Journal of Cultural Economy*, *12*(6), 571–589.

Walrave, B., Talmar, M., Podoynitsyna, K. S., Romme, A. G. L., & Verbong, G. P. J. (2018). A multi-level perspective on innovation ecosystems for path-breaking innovation. *Technological Forecasting and Social Change*, *136*(December 2016), 103–113.

WCED. (1987). *Our Common Future. Report of the World Commission on Environment and Development: Our Common Future.* Oxford: Oxford University Press.

Weber, K. M., & Rohracher, H. (2012). Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive "failures" framework. *Research Policy*, *41*(6), 1037–1047.

Wessner, C. (2005). *Entrepreneurship and the innovation ecosystem policy lessons from the United States. Entrepreneurship, Growth and Public Policy*. Boston, MA: Springer.

Wijaya, T., Vasirani, M., & Aberer, K. (2014). *Crowdsourcing Behavioral Incentives for Pervasive Demand Response*. Lausanne, Switzerland.

Wirth, H., & Schneider, K. (2016). *Recent facts about photovoltaics in Germany*. *Fraunhofer ISE*. Freiburg.

Wittmayer, J. M., Avelino, F., van Steenbergen, F., & Loorbach, D. (2017). Actor roles in transition: Insights from sociological perspectives. *Environmental Innovation and Societal Transitions*, *24*(September), 45–56.

Wolf, M., & McQuitty, S. (2011). Understanding the do-it-yourself consumer: DIY motivations and outcomes. *AMS Review*, *1*(3–4), 154–170.

Wolske, K. S., Stern, P. C., & Dietz, T. (2017). Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories. *Energy Research and Social Science*, *25*, 134–151.

Wüstenhagen, R., Markard, J., & Truffer, B. (2003). Diffusion of green power products in Switzerland. *Energy Policy*, *31*(7), 621–632.

Wustenhagen, R., Wolsink, M., & Burer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy*, *35*(5), 2683–2691.

Wustenhagen, R., & Wuebker, R. (Eds.). (2011). *The handbook of research on energy entrepreneurship*. Cheltenham, UK: Edward Elgar Publishing.

Yee, N. (2006). Motivations for play in online games. *Cyberpsychology & Behavior*, *9*(6), 772–775.

Ympäristöministeriö. (2017). *Kohti ilmastoviisasta arkea - Valtioneuvoston selonteko keskipitkän aikavälin ilmastopolitiikan suunnitelmasta vuoteen 2030* (No. 21/2017 Ympäristöministeriön raportteja).

Yves, H., & Teufel, S. (2017). Prosumer communities: Electricity as an interpersonal construct. In *2016 International Conference on Smart Grid and Clean Energy Technologies, ICSGCE 2016* (pp. 89–94).

Zhou, B., Li, W., Chan, K. W., Cao, Y., Kuang, Y., Liu, X., & Wang, X. (2016). Smart home energy management systems: Concept, configurations, and scheduling strategies. *Renewable and Sustainable Energy Reviews*, *61*, 30–40.

Zhou, S., & Brown, M. A. (2017). Smart meter deployment in Europe : A comparative case study on the impacts of national policy schemes, *144*, 22–32.

PUBLICATIONS

PUBLICATION I

The role of residential prosumers initiating the energy innovation ecosystem to future flexible energy system.

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The role of residential prosumers initiating the energy innovation ecosystem to future flexible energy system

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***Abstract*— This paper explores prosumer role in Smart Grid innovation ecosystem as part of the energy market transition from traditional energy system to future flexible energy ecosystem based on renewable energy sources. This transition is facilitated by international agendas and government actions to slow down climate change globally and technological advancements in multiple areas like consumer electronics (e.g. smart appliances) and Information and Communication Technologies (ICT). These developments render industries to converge and traditional structures are changing. Despite the technology developments and top-down policy push, the Smart Grid innovation ecosystem diffusion has not reached mass-market adoption yet. We review theoretical basis for energy system transition based on which we suggest a series of exploratory propositions for prosumer role in initiating the Smart Grid innovation ecosystem.**

***Index Terms*-- Flexible electrical energy system, Smart Grid, innovation ecosystem, diffusion of innovation, prosumer, demand response**

I. INTRODUCTION: SMART GRIDS AS BASIS FOR FLEXIBLE ENERGY ECOSYSTEM

Energy markets and power systems are in rapid transition due to increased use of renewable energy sources, energy efficiency requirements, tightened regulation, and need for business profitability. Smart Grid distribution grids are customer-driven marketplaces for customers having active resources (e.g. storages). In general, Smart Grids have two key purposes [1]: *Enabling energy-efficient and environmentally friendly energy market* (interactive customer interface, integration of active resources, demand response, common market models and comprehensive ICT solutions) and *providing critical infrastructure for society* (fault and major disturbance management, self-healing networks, island operation and micro-grids).

One of the most significant missing links in technology has been two-way communication between utilities and end-customers. Implementation of Advanced Metering Infrastructure (AMI) is now solving partly this problem. Demand response (DR) functions become achievable, and the efficient use of the existing network and energy resources by market mechanisms can be improved by making the end user connection point more flexible and interactive. Interactive customer gateway opens up possibilities for Smart Grid ecosystem actors to offer new kinds of value added services to end customers. Figure 1 proposes the concept of the interactive customer gateway [2].

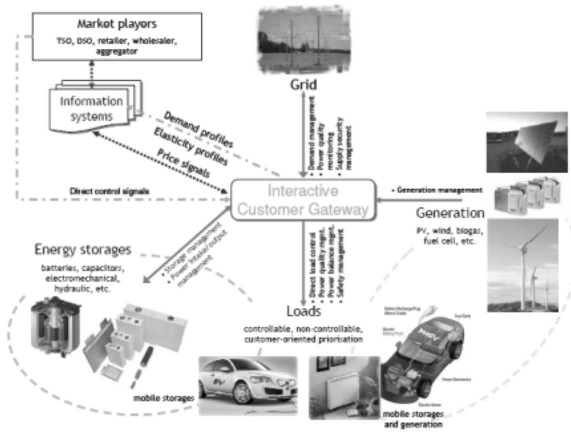


Figure 1. Concept of the interactive customer gateway

In order for the Smart Grid to succeed and fulfill it's efficiency and sustainability goals it needs a large and dynamic prosumer base. Despite the heavy investments in the Smart Grid technology, little evidence can be found on effective prosumer management schemes, proactively grouping the prosumers and comprehensive prosumer rewarding schemes [3].

II. THEORETICAL FRAMEWORK FOR ENERGY SECTOR TRANSITION TOWARDS FLEXIBLE ENERGY SYSTEM

A. *Socio-Technical multilevel approach*

The ongoing energy industry transition involves complex developments in technology, business models, society and policy-making. A major industry transition like this includes changes in multiple levels of society and can be modeled using socio-technical transition with multilevel perspective [4]. In the socio-technical approach, 'Landscape' refers to macro-economy, political ideologies, demography and national conditions, 'Regime' relates to existing and well-shaped industries, technologies, culture and policy and 'Niche' means emerging technologies and innovations [5]- [6].

In the socio-technical approach, steering of the energy system transition - in the form of environmental incentive structures, policy interventions, regulations and taxation - takes place in the landscape level and poses pressure for change in the regime (in this case the established energy markets). Innovation and technological change take place at the niche level where new technologies are developed and novel business concepts arise to challenge the old customs of the regime dominated by large companies, long-standing processes and established business models. In terms of flow of the industry transition, a technology niche first progresses to a market niche and then enables a regime shift [7]. Niche development can be also seen progressing at local level in several markets and cumulating towards a global niche [8]. Both of these developments can be observed in the Smart Grid case today.

Technology evolution towards more flexible energy systems requires new intelligent components to be added to power grid and two-way communication between the components. Internet of Energy (IoE) has a lot of similarities to Internet and ICT development in the 1970s and 1980s [9]. It has been estimated that the potential for information technology to reduce carbon emissions through Smart Grid technology could be up to 15% of total CO_2 emissions in the power sector [10].

As new technology solutions emerge, new actors and stakeholders come into play. *Prosumer* emerges as a new actor in the energy markets and can be defined as being both consumer and producer of energy. *'Prosumption involves both production and consumption rather than focusing on either one (production) or the other (consumption)'* [11]. Prosumer can be seen as a Niche actor within the Smart Grid innovation ecosystem in the socio-technical framework. Different levels of the industry transition affect consumers who need to weigh future options to fulfill their energy needs.

Drivers for starting prosumption [12] can include: *Economic drivers*; system costs, electricity rates, self consumption ration, quality of energy resource (e.g. solar); *Behavioral drivers*; environmental values, control, self-sufficiency, reliability and safety, status and prestige, interest in technology, desire for choice; *Technology drivers*; technology improvements, batteries, electric vehicles, energy efficiency trends, load management, smart-grid infrastructure; and *National conditions*; available (roof) space, share of rental property, national energy demand, existing and planned energy development, connection to energy infrastructure In addition, *ethical aspects* have an impact on prosumer movement; for example in Finland there has been wide spread discussion over the monopolistic nature of electricity delivery networks resulting as unexpected and substantial increases in energy price levels as well as tax payments flooding overseas due to profit maximization of the large international energy regime actors [13]. The prosumers also face *barriers* that are related to privacy and security concerns, need for behavioral change, lack of business models, complexities of new technologies and risky cost/benefit structures [14]. Figure 2 illustrates the energy market socio-technical framework.

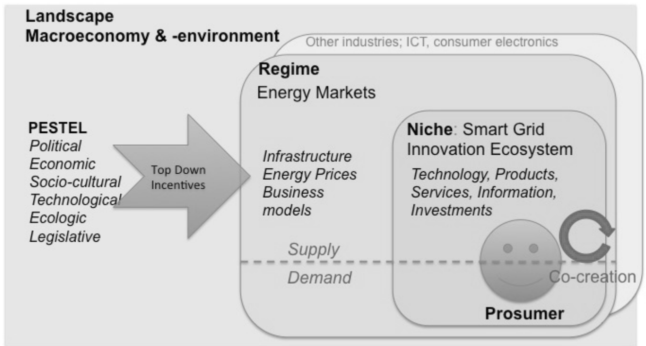


Figure 2. Energy market transition and prosumer

B. *Diffusion of innovation and the Smart Grid*

Innovation ecosystem, in our case the Smart Grid niche, contains interaction, flow of knowledge and technologies between actors who are needed in order to turn new ideas into new processes, products or services. Each actor in innovation ecosystem contributes to the ecosystem's overall wellbeing and development; the existence and success of each ecosystem member is influenced as a whole entity that is in constant evolution [15]. According to Moore [16], the organizations "*co-evolve capabilities around a new innovation by working cooperatively as well as competitively in the creation of products and services*".

Diffusion of innovation is a process describing spread of innovations over time. Innovation is adopted among categories of adopters in temporal sequence, namely Innovators, Early Adopters, Early Majority, Late Majority, and Laggards [17].

Before reaching mass market the innovation needs to be accepted by early market adopters (innovators and early adopters). Most innovations in fact never make it across 'the chasm' [18] between the early and the late markets and fall in to a valley of death [19].

Rogers summarizes [17] that innovation diffusion occurs in stages of individual's adoption: knowledge, persuasion, decision and confirmation. For the present paper the most relevant are the factors that affect the *decision* to adopt or reject an innovation. These factors, as presented by Rogers [20] are relative advantage, compatibility, complexity, trialability and observability.

Relative advantage refers to benefits compared to the costs of adopting a new technology. Costs include financial costs but also concerns related to e.g. risks, complexity or trade offs in functionality. For prosumers in the Smart Grid case, privacy concerns or worries about the energy quality may be very relevant and will affect the perceived relative advantage of the technology [21]. *Compatibility* means how well the new technology fits with the individuals existing way of operating. The need to change one's behavior can lower the interest to adopt the new technology especially in the mass-market [20] Becoming a prosumer undoubtedly requires a change in behavior. Environmental reasons has been one of the main arguments for behavioral change needed to into use Smart Metering [22]-[23]. Another known reason for users to change behavior is price incentives [24]. *Complexity* is not for everyone and very complex products have generally slower adoption rates than less-complex ones [20]. Early adopters are better at dealing with complexity while the mass-market users appreciate ease of use [20]. *Trialability* probes whether the end-user is able to test the innovation in a risk-free setting with minimal costs. For example availability of lease vs. buy options may lower the threshold for testing a new solution. Trialability is important especially for the early market users who are interested in trying new technologies and giving feedback [20]. *Observability* on the other hand is more important for the mass-market adopters, who are interested in turnkey solutions and rely on word of mouth recommendations of other similar users [20].

III. Proposition development for prosumer role in initiating Smart Grid innovation ecosystem

Based on the theory review presented above, we have developed seven preliminary propositions for prosumer role in initiating the Smart Grid ecosystem.

Macro-level policy push is often needed to support environmental innovations and enabling technology development [25]-[26]. An example of a top-down policy push is AMI implementation in Finland. In practice almost all customers (98 %) are provided with a new AMR meter in 2016 due to legislation. The law for example requires the AMR meters provide hourly energy measurement, registrations of quality of supply and demand response functionality [2]. AMI system implementation is not only energy remote reading, but it enables real time two-way communication between customers and other actors and offers huge amount of data for developing new functions for Smart Grids. AMI system with relating ICT systems and business processes form a larger entity to create added value for customers, DSO, energy retailer and service providers [2].

Even though the technology infrastructure is largely in place and in use in DSOs, the customer adoption rates for AMI –based new innovations remain low in Finland. According to the Energy Authority in Finland, the customer adoption rate for hourly Spot electricity price model is growing but still represents less than 10 % of all electricity agreements in 2016. Despite the strong push from macro-level, both policy makers and energy specialists emphasize that the renewable energy markets should become self-sustaining [27]. More innovative approach to diffusion can be supported by a innovation policy focusing on finding solutions to local energy challenges [28]. This way the relevance of using renewables becomes more sensible for the end users. So far the top-down initiatives in the electricity markets have not built a self-sustaining Niche. Hence, we propose that

P1: Top-down macro-level actions to push the Smart Grid ecosystem are ***necessary*** *enablers for the technology development, removing barriers and lowering the adoption threshold but they are not* ***sufficient*** *alone to guarantee the Smart Grid success among end users.*

The Smart Grid business ecosystem is still taking form and the current consumer offering is complex lacking e.g. availability of turnkey solutions in most markets. There are also privacy, quality and security issues. A complete solution needed to boost the mass-market adoption does not exist today. Despite positive growth estimates for prosumption there are only about 50 small-scale prosumers [29] (i.e. about 0,1 % of all the DSO's customers [30]) connected to the power grid in Helsinki area (Finland), most of which are producing energy for their own use only. Comparable situations can also be observed in other markets globally. It seems fair to say that the Smart Grid ecosystem is currently progressing towards being a market niche. Hence, we propose that

P2: Smart Grid prosumption adoption is in the ***early market phase*** *globally and is currently adopted by early market prosumers.*

The decision to become a prosumer in the early market is more often based on perceived relative advantage of new functionality rather than financial investment costs. Also in the field of environmental innovations, ability to use green energy can be seen as a justification to higher cost [31] signifying the attitude of early markets. Some of the early market prosumers are interested in new technology solutions in general and others may be more driven by ability to take green technologies into use. However, these early market users are eager to get access to new technology despite higher investment cost and risks associated. Some of the early market adopters are seeing themselves as key contributors to technology development and want to get involved. Innovators and early adopters are generally more concerned about the technical performance and are willing to invest in installing and using new technology. A good example of early market prosumers functionality testing of Smart Grid related innovation is implementation of EVs with communal service companies and technology development of charging stations and batteries. Based on the above we propose that

P3: Early market prosumer role is to ***test functionality and relative advantage*** *of Smart Grid innovations.*

Early market prosumers are prepared to pay more for new technology if they see it will provide benefits the established technologies cannot deliver [32]. For instance, early adopters in Finland have various motives for their investment including interest in technology, self-sufficiency, energy efficiency, reputation, environmental concerns and cost savings [33]. The early adopters are also interested in the balance between capital expenditure (CAPEX) and operational expenditure

(OPEX) since this is part of the full performance of the innovation. The financial attributes can include investment and installation cost (CAPEX), energy price and maintenance and operational costs (OPEX). Therefore, early markets test these financial and non-financial aspects that later become important decision making attributes for the subsequent adoption categories. Following the above we propose that

*P4: Early market Prosumers role is to test **financial benefits** of innovations and they are interested in Smart Grid innovations that exhibit same or higher levels of CAPEX than existing energy solutions while OPEX may remain risky.*

An example of an innovation going through early market testing is electricity storage technology for domestic use. Some companies have brought Li-ion battery technology based electricity storage products to the market, The initial investment cost of the battery packs can be considered high [34] and OPEX related issues remain undetermined.

In the long run, all end user categories are interested in managing OPEX and especially mass markets will be heavily influenced by the energy price developments and payback time calculations for their investments. A rational prosumer assumes that once the technology is mature the system will enable reduced energy bill over current situation. The prosumer will expect the energy prices will go down by optimizing the use of electricity through efficiency measures (e.g. using off-peak hours and prices), producing energy for own use, storing energy for later use and potentially trading excess energy. Consequently, we propose that

*P5: The role of early market prosumers is to **validate** Smart Grid innovations that exhibit lower levels of OPEX and same or lower CAPEX than existing energy solutions so that late market prosumers can adopt these innovations.*

Early market prosumers are interested in new technologies and are keen to get involved with early products [20]. They are willing to make compromises on functionality since, as visionaries, they can foresee the benefits of the new technology better than later categories and are willing to contribute to development of solutions that better match the mass-market needs. Smart Grid's shortages in prosumer related functionality, business models and availability are not necessarily stopping the early adopters becoming prosumers. Prosumption also gives them a possibility to become influential opinion leaders in their social networks. In Finland there have been no incentives like feed-in-tariff for small-scale PV panels but still there are already residential early market prosumers who have installed their own panels even they are not yet mass products. Hence, we propose that

*P6: The role of early market prosumers is **to tinker with technology** and be **opinion leaders** as they are tolerant to technical difficulties and complexities of early versions of innovations.*

In order for the diffusion to reach the mass-market, the product needs to change: the early majority will not tolerate complex do-it-yourself type of offering. This is the critical point of diffusion as a whole product meeting the mass-market customer needs is required [18]. As of today, the Smart Grid prosumer offering lacks clarity on business models, privacy and security aspects and availability of turnkey solution. Focusing efforts on ramping up effective co-creation activities with the early market prosumers to fine-tune the offering could speed up the Smart Grid diffusion.

Co-creation with early market prosumers to define whole product for mass markets could be critical for Smart Grid success as this market segment is willing and able to give feedback and proposed improvements. Technical improvements are achieved during the diffusion phase through user feedback or re-invention (see Rogers, 1995). The early market lead users, especially the innovators, on the other hand can require a substantial amount of technical support and very detailed customization thus eating out the supplier resources from the product development for the mass markets. However, adequate resources should be in place to learn early from the markets [35]. We propose that

*P7: The early market prosumers role as **co-creators** with technology developers and pioneering companies can lead to improvements needed in the **whole product** to satisfy the mass market needs and initiate the ecosystem growth.*

IV. Conclusions

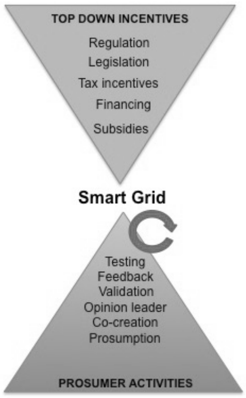
Smart Grid ecosystems are in early market phase globally. Top down approach in the form of tax incentives, subsidies and regulation drives Smart Grid adoption but the actual success of the Smart Grid will highly depend on activating prosumers. The early market involvement is essential for innovation take off. Macro-level actions already taking place, bottom up activation of early market prosumers is the next step in Smart Grid technology diffusion and industry transformation towards flexible energy systems. The bottom-up activities can include validating new business models (e.g. success of leasing solar panels in USA), testing and giving feedback on technology and co-creational activities to innovate and improve the offering for mass market. The next industry focus should be in systematically activating early market prosumers and whole product development for mass market in co-operation with the other ecosystem actors.

The research is limited at this stage to theoretical proposition development and will require further quantitative validation. The quantitative measures could include testing of e.g.: how much policy actions reduce prosumers' price, percentage of current vs. potential adopters, what percentage of early prosumers are testing and communicating functionality to others, measures of CAPEX/OPEX balance among early prosumers, do the prices drop as early markets adopt innovations, and what percentage of early prosumers engage in co-creation. This paper contributes to future research by introducing propositions, which, once tested, can be further developed into hypothesis related to the early market prosumer role in Smart Grid ecosystem diffusion.

Summary of the prosumer role related to the propositions and to the socio-technical framework is presented in Table 1.

TABLE I. PROSUMER ROLE IN INITIATING THE SMART GRID INNOVATION ECOSYSTEM RELATED TO THE PRELIMINARY PROPOSITIONS AND TO SOCIO-TECHNICAL FRAMEWORK

#	Prosumer role	Regulatory		Prosumer
		Macro	Regime	Niche
P1	Prosumption	x		
P2	Early market actor			x
P3	Test functionality & relative advantage		x	x
P4	Test financial benefits			x
P5	Validate business models		x	x
P6	Feedback on technology. Be opinion leader.	x		x
P7	Co-creation	x	x	x



REFERENCES

[1] P. Järventausta, P. Verho, J. Partanen, and D. Kronman, "Finnish Smart Grids - A migration from version one to the next generation," in Proceedings of the 21st International Conference on Electricity Distribution, 2011.

[2] P. Järventausta, "Smart Grids with large scale implementation of Automatic Meter Reading - Experiences from Finland.," in the Handbook of Clean Energy Systems, John Wiley & Sons, Ltd, 2015.

[3] A. J. D. Rathnayaka, V. M. Potdar, and S. J. Kuruppu, "An innovative approach to manage prosumers in Smart Grid," 2011 World Congr. Sustain. Technol., pp. 141–146, 2011.

[4] F. W. Geels and J. Schot, "Typology of sociotechnical transition pathways," Res. Policy, vol. 36, no. 3, pp. 399–417, 2007.

[5] F. W. Geels, "The multi-level perspective on sustainability transitions: Responses to seven criticisms," Environ. Innov. Soc. Transitions, vol. 1, no. 1, pp. 24–40, 2011.

[6] R. Kemp and A. Rip, Technological change. Battelle Press, 1998.

[7] M. Weber, R. Hoogma, B. Lane, and J. W. Schot, Experimenting with sustainable transport innovations: a workbook for strategic Niche management. Seville/Enschede: Universiteit Twente., 1999.

[8] F. W. Geels and R. P. J. M. Raven, "Non-linearity and expectations in Niche-development trajectories: ups and downs in Dutch biogas development (1973–2003)," Technol. Anal. Strateg. Manag., vol. 18, no. 3, pp. 375–392, 2006.

[9] S. Karnouskos, "The cooperative internet of things enabled Smart Grid.," in Proceedings of the 14th IEEE international symposium on consumer electronics (ISCE), 2010, pp. 7–10.

[10] The Climate Group, "SMART 2020 : Enabling the low carbon economy in the information age," 2008.

[11] G. Ritzer and N. Jurgenson, "Production, Consumption, Prosumption: The nature of capitalism in the age of the digital 'prosumer,'" J. Consum. Cult., vol. 10, no. 1, pp. 13–36, 2010.

[12] IEA-RETD, "Residential Prosumers - Drivers and Policy Options (RE-Prosumers)," 2014.

[13] "Carunan omistaja mainoksessa: Monopoli varma sijoitus, koska hintoja voi nostaa," Taloussanomat, 2015. [Online]. Available: http://www.taloussanomat.fi/energia/2016/02/05/carunan-omistaja-mainoksessa-monopoli-varma-sijoitus-koska-hintoja-voi-nostaa/20161434/12.

[14] G. P. J. Verbong, S. Beemsterboer, and F. Sengers, "Smart grids or smart users? Involving users in developing a low carbon electricity economy," Energy Policy, vol. 52, pp. 117–125, 2013.

[15] M. Iansiti and R. Levien, "Strategy as ecology.," Harv. Bus. Rev., vol. March, pp. 1–10, 2004.

[16] J. F. Moore, "Predators and prey: A new ecology of competition," Harv. Bus. Rev., vol. May-June, pp. 75–86, 1993.

[17] E. M. Rogers, Diffusion of Innovations (first edition)., 1st ed. Free Press of Glencoe, 1962.

[18] G. A. Moore, Crossing the Chasm. Harper Business Essentials, 1991.

[19] E. L. J. Mills, "Traversing the valley of death.," Forbes Online, 2005. .

[20] E. M. Rogers, Diffusion of Innovations, 4th ed. Schuster: Free Press, 1995.

[21] P. McDaniel and S. McLaughlin, "Security and privacy challenges in the Smart Grid.," IEEE Secur. Priv., vol. 3, pp. 75–77, 2009.

[22] J. Burgess and M. Nye, "Re-materialising energy use through transparent monitoring systems," Energy Policy, vol. 36, no. 12, pp. 4454–4459, 2008.

[23] S. Darby, "The effectiveness of feedback on energy consumption. A Review for DEFRA of the Literature on Metering, Billing and direct Displays," Environ. Chang. Inst. Univ. Oxford, vol. 22, no. April, pp. 1–21, 2006.

[24] R. M. J. Benders, R. Kok, H. Moll, G. Wiersma, and K. J. Noorman, "New approaches for household energy conservation. In search of personal household energy budgets and energy reduction options.," Energy Policy, vol. 34, pp. 3612–3622.

[25] M. E. Porter, "America's Green strategy." Sci. Am., vol. 264, p. 168, 1991.

[26] R. Kemp and S. Pontoglio, "The innovation effects of environmental policy instruments — A typical case of the blind men and the elephant?" Ecol. Econ., vol. 72, pp. 28–36, 2011.

[27] K. L. Shum and C. Watanabe, "Towards a local learning (innovation) model of solar photovoltaic deployment," Energy Policy, vol. 36, no. 2, pp. 508–521, Feb. 2008.

[28] T. D. Tsoutsos and Y. A. Stamboulis, "The sustainable diffusion of renewable energy technologies as an example of an innovation-focused policy," Technovation, vol. 25, no. 7, pp. 753–761, 2005.

[29] "Pientuotannon verkkoon syöttäminen on helppoa," Helsingin Sanomat, 2015. [Online]. Available: http://www.hs.fi/mielipide/a1448945981659.

[30] "Asuntokunnat koon ja asunnon talotyypin mukaan 1985-2014.," Tilastokeskus. [Online]. Available: http://pxnet2.stat.fi/PXWeb/pxweb/fi/StatFin/StatFin__asu__asas/010_asas_tau_101.px/table/tableViewLayout1/?rxid=d48d4536-4a51-45e7-9ac4-df748e075e21.

[31] J. P. Roberts and K. Alston, "Partners in new product development: SC Johnson and the alliance for environmental innovation.," Corp. Environ. Strateg., vol. 6, no. 2, pp. 110–128, 1999.

[32] M. Laroche, J. Bergeron, and G. Barbaro-Forleo, "Targeting consumers who are willing to pay more for environmentally friendly products," J. Consum. Mark., vol. 18, no. 6, pp. 503–520, 2001.

[33] N. A. Nygren, P. Kontio, J. Lyytimäki, V. Varho, and P. Tapio, "Early adopters boosting the diffusion of sustainable small-scale energy solutions," Renew. Sustain. Energy Rev., vol. 46, pp. 79–87, 2015.

[34] R. Martin, "Home Energy Storage Enters a New Era.," MIT Technology review, 2015. [Online]. Available: https://www.technologyreview.com/s/541336/home-energy-storage-enters-a-new-era/.

[35] S. J. Mäkinen, J. Kanniainen, and I. Peltola, "Investigating Adoption of Free Beta Applications in a Platform-Based Business Ecosystem," J. Prod. Innov. Manag., vol. 31, no. 3, pp. 451–465, 2014.

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Prosumer centric digital energy ecosystem framework

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Prosumer centric digital energy ecosystem framework

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ABSTRACT

Climate change is putting pressure on governments, policy makers and international organizations to increase energy efficiency and move towards using renewable energy sources. To meet growing need for energy and at the same time comply with ecologic and economic demands, the energy market structure is slowly transitioning from a centralized system to more interactive and decentralized model based on Smart Grid technology in which also end users may play a role as prosumers i.e. as producers and consumers of energy. Different scenarios exist for the level of prosumer participation in the future flexible energy ecosystem. In this paper, we propose a framework for *Prosumer centric Digital Energy Ecosystem* based on Smart Grid technologies, decentralized energy production using renewable energy sources and complex network of new and incumbent actors, business models and processes.

CCS concepts

• Social and professional topics→ Professional topics→ Computing and business→ Socio-technical systems

Keywords

Smart Grid; digital business ecosystem; prosumer; open innovation; user led innovation; co-creation

1. INTRODUCTION – ENERGY MARKETS IN TRANSITION TOWARDS FLEXIBLE ENERGY SYSTEMS

Energy systems globally are in a process of profound transformation due to requirement to dramatically reduce carbon emissions, improve energy efficiency and move to renewable energy sources. Energy production must be more flexible with intermittent generation and must allow for the optimized management of the production and consumption of electricity and heat. This necessitates new technology components and business models. Smart Grid technology introduces the required intelligence to the power grid and enables flexibility, allows close to real time pricing as well as bi-directional communication and energy flows between suppliers and consumers. Smart Grid has two main functions: an) *enabler* of energy-efficient and environmentally friendly energy market and b) *critical infrastructure* of society offering uninterrupted power supply [1]. At the same time commoditization, integration and affordability of information and communication technologies (ICT) have led to wide spread digitalization and convergence creating the open, global network connecting people, information, and things- Internet of Things (IoT). Integration of the IoT into the energy system opens up a whole new way for management of the energy system. Internet of Energy (IoE) enables innovative ways of power distribution, energy storage, grid monitoring and communication as it enhances the transfer of energy and data bidirectionally.

In addition to new technologies, the business environment is changing and new actors emerge in the energy industry. Prosumers are consumers that also act as producers of energy. A prosumer can be an individual person as household level customer, a larger building (e.g. apartment building or shopping center), business entity like organization or a firm, or other kind of community. Prosumer may assume different level of activities that can vary from producing energy for own use to sharing excess energy through the grid and becoming an active participant in the energy industry. In this article we are exploring prosumer role as a value-creating actor in the developing energy ecosystem. Our research objectives are: RO1 - How should a digital energy ecosystem be defined; RO2 - How does the prosumer fit into the digital energy ecosystem?

2. THEORY REVIEW

2.1 Socio-Technical Multi-Level Framework

Industry transitions can be modeled using *socio-technical multilevel framework* [2] which is presented from the Smart Grid and energy ecosystem perspective in Figure 1.

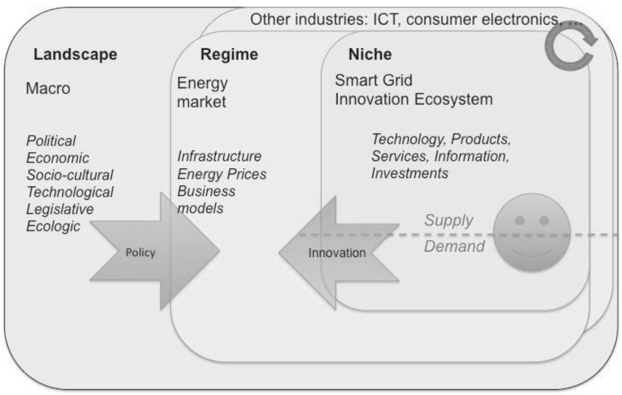

Figure 1. Socio-technical multilevel framework [3], [2].

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The transition of energy industry is systemic, complex and takes place on different levels of society and technology. In the socio-technical multilevel framework, the landscape represents macro – level that steers (using policies and regulations) the energy regime evolution from centralized and monopolistic system towards more flexible and decentralized model based on renewable energy sources (RES). New technology development takes place at niche level where innovations add intelligence and robustness to the energy system. Smart Grid technology is largely based on ICT and enables new value creation opportunities and allows new players to enter the industry but also poses risks to the incumbent players that are tied to heavy investments in legacy infrastructure and established business models. This means that the energy industry dynamics is in flux.

2.2 Changing Industry Dynamics

Porter's [4] *industry forces* has been one of the seminal theories explaining industrial dynamics. In its core, competitive forces are driven by the power of suppliers and customers in the value chain. The out of industry dynamics originated from potential new entrants or new products or services.

Freeman's stakeholder view [5] already identifies e.g. environmentalists and consumer advocates as actors impacting firms and industries. Schumpeter [6] discussed earlier the prerequisite of socio-economic and political factors for technological innovation to achieve *creative destruction*. Many of the technological innovations where consumer becomes prosumer are not disruptive in a sense that Christensen [7] meant. Energy can be produced with established methods but the ability to connect production and consumption makes the difference. This creates analogy of the amount of connection and economic value that Metcalfe [8] coined in Internet context. One could argue that connectivity, or internet of energy (IoE), represents such a change of paradigm that Dosi [9] referred to as a source of discontinuity.

Natural inertia can explain whether an industry is conservative. Natural inertia means here long-time factors not dependent on any current or new actor wishing to introduce something new. Asset heavy industries like mining or energy plant construction possess logically such features. Developing a new mine, paper factory or nuclear power plant takes time. Planning and implementation is often shaped the availability of investment and regulatory requirements regarding possible competition issues and safety or environmental impact. Software industry is fundamentally different in this respect. The product is intangible and it can be scaled up globally in real time. The ICT industry has been pivotal in recent theories of industrial convergence [10].

The second category of inertia can be called *perceived*. It deals with the issues where fundamental source is beliefs – individual and collective. Current "correct way" of doing things can be called *industry recipe* [11] or *dominant logic* [12]. AirBnB, Momondo, Uber and many other software intensive start-ups have recently proved that the roles of customers and suppliers can change dynamically and fast growth can be initiated with an innovative approach. The incumbent actors in the energy regime have been traditionally slowing down the transition; heavy investments in energy infrastructure pose risks in the changing environment. Can ecosystem type of working methods be applied to the energy sector so that prosumers as a group could produce energy with such scale and speed that weighs when estimating the influence of the prosumer concept? Prosumer market or distributed electric networks are attractive for renewals and this has created a *halo* [13] effect. This makes it harder for incumbents not to participate.

2.3 Ecosystems

In a business ecosystem participating actors depend on each other for survival – and success. Moore defines *business ecosystem* as "an economic community supported by a foundation of interacting organizations and individuals." [14]. A *digital ecosystem* can be described as a self-organizing digital infrastructure for creating a digital environment for organizations that 'supports the cooperation, the knowledge sharing, the development of open and adaptive technologies and evolutionary business models' [15]. Chang and West [16] associate digital ecosystems and biological ecosystems by describing the digital ecosystem actors as biological, economic (organizations) and digital (digital platforms) species and propose that underlying technologies and services support the digital ecosystems.

Digital business ecosystem (DBE) combines both business ecosystem (economy) and digital ecosystem (digital representation of economy) [17]. According to World Economic Forum definition, the digital business ecosystem is: "… the space formed by the convergence of the media, telecoms and IT industries. It consists of users, companies, governments and civil society, as well as the infrastructure that enables digital interactions." DBEs are based on *industry convergence* (ICT technology) and *openness* (open innovation, open standards, open source software, open APIs) enabling innovation and value creation among the ecosystem actors.

Adner [18] describes *innovation ecosystem* as 'the collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution.' Wessner [19] considers innovation ecosystem as the national innovation system in which 'complex synergies between collective efforts among stakeholders bring innovation to the market'. Oh et al. [20] have summarized the characteristics of innovation ecosystem (when compared to other ecosystems) as being more explicitly systemic, based on digitalization and open innovation, having media appeal of 'innovation ecosystem' –term and accentuating the important role of 'niches'.

2.4 User Centric Innovation Models

Taking action to halt carbon emissions necessarily involves a number of parties in an attempt to make renewable energy ecosystem viable. There are several characteristics that are commonly linked to environmentally sustainable innovations: Large group of consumers need to adopt the innovation to make it successful [21]; Macro –level policy-induced financial and regulatory incentives are commonly used to accelerate the diffusion of environmentally important technology innovations; There may be willingness to pay more for environmental innovations due to environmental awareness [22]; Consumer behavioral change is required in order to fully take into use the environmental innovation [23]. E.g. changing one's behavior for environmental reasons has been one of the main arguments for e.g. taking into use Smart Metering [24]-[25].

To understand this type of networked innovation for example the traditional Triple Helix model of innovation focuses on the co-operation between universities, the industry and governments [35]. *Quadruple Helix* model expands the Triple Helix by adding the fourth helix: civil society [36]. *Quintuple Helix* is yet more comprehensive by adding the perspective of the 'natural environments of society' so that nature becomes recognized as an essential and equal element in the innovation and knowledge system [37].

From the process point of view, the traditional way of innovating is based on internal company processes, subcontracting and control whereas the new innovation modes increasingly rely on involving external stakeholders, including customers and even whole ecosystems, in the innovation process. Open innovation [26] can include various methods and levels of openness which can be divided into outside-in, inside-out and coupled. Examples of the *outside-in* process include for example crowdsourcing [27], and mass customization. *Inside-out* strategy conveys the locus of innovation to the market place and hopes to accelerate innovation development by external partiers. *Coupled* process combines elements of both outside-in (gain external knowledge) and inside-out (bring ideas to markets) and is often called *co-creation.* Co-creation means bringing together different parties for example, a company and a group of customers, in order to jointly produce a mutually valued outcome [28]. Collaborating and co-creating with lead users is called *user centric innovation* or *user led innovation* [29]. It has been found that user led innovations seem to create commercially attractive solutions to the market place [30]. *Strategic niche management* [31] considers user centric innovation as part of the socio-technical transition. Kristensson et al. have developed *strategies for successful user involvement in technology based services* [32] that stress for instance taking into account that users are a heterogeneous group, mainly motivated through real life use cases and not necessarily technology savvy. Living labs [33] are often residential communities in which the people are observed in real life situations and engaged in co-creational activities. Smart City projects are another flourishing type of projects integrating many industries.

3. DIGITAL ENERGY ECOSYSTEM PROPOSITIONAL FRAMEWORK

To describe the digital energy ecosystem (RO1), we propose a *prosumer centric Digital Energy Ecosystem Framework* (pDEEF). The framework is presented in Figure 2.

3.1 Actors

According to the Quintuple innovation model, industry, citizens, regulators, academia and natural environment are all part of the innovation ecosystem. Socio-technical multilevel framework also assumes the importance of landscape level (macro environment) influence on innovation development taking place at the niche level. *Regulators* in our model represent the macro level and include for instance international organizations, European Union, national governments and municipalities. In addition, the *Natural environment* is considered as an integral part of the ecosystem in the energy production and consumption cycle.

In the energy markets there are *incumbent energy industry actors* e.g. distribution service operators (DSO), transmission service operators (TSO), Service Providers, Energy Retailers, installation and maintenance providers. There are also n*ew actors* in the including prosumers, aggregators, Smart Meter and home energy management system (HEMS) manufacturers, PV equipment manufactures, and storage manufacturers. Due to industry convergence, *new entrants from other sectors* are entering the energy market and include e.g. value added service (VAS) developers, end user equipment (mobile devices) manufacturers, ICT manufacturers, data management firms, independent software vendors (ISV) and telecom operators.

*Digital actors (*or *platforms)* in our framework contain hardware and software platforms i.e. smart meters, energy storage, HEMS, ICT infrastructure, ICT platforms, Smart Grid infrastructure, data hubs, web gateways, end user devices and user interfaces, development tool kits, sensors, home automation devices etc.

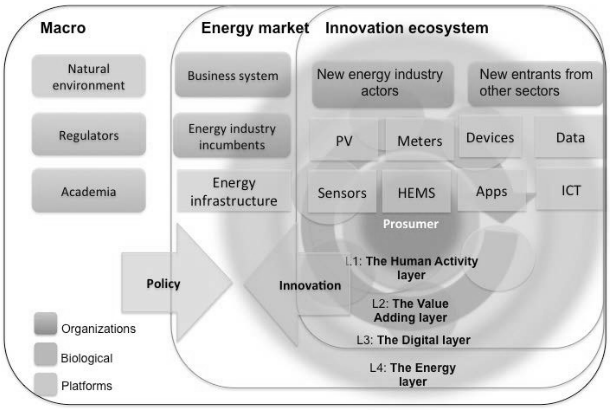

Figure 2. Prosumer centric Digital Energy Ecosystem Framework (pDEEF): actors and layers

3.2 Layers

We approach the question (RO2) 'how the prosumer fits into the digital energy ecosystem?' through outlining four layers for the digital energy ecosystem. The framework is based on simplified presentation of IoT layers (see e.g. [34]) completed with energy processes, value adding activity and human action.

L1: The Human Activity Layer – Prosumer, a new actor in the energy ecosystem can be either active or passive from ecosystem point-of-view. Most existing scenarios for prosumer 'activity' focus on energy efficiency and demand side management (DMS) [35] or, to in increasing amount, in prosumer community involvement [36]. An active prosumer can participate in energy production but could also get involved in innovation and value creation processes. Prosumers get access to innovation opportunities through various digital touch points including web, mobile devices (smart phones) and applications, user interfaces, web portals and billing system. The Human Activity Layer is closely interlinked to the next layer, L2: The Value Adding Layer.

L2: The Value Adding Layer – Process, activities and functions added applications and services. L2 consists of applications, processes and business models. Digital touch points connect the prosumers to core areas of energy market processes related to technology enablers, energy generation, business models, data monitoring, data analytics and value added services. The prosumer will have touch points to various aspects of physical and financial energy flows. Using digital tools (crowdsourcing platforms, virtual co-creation environments, toolkits, smart phones, web interface) the prosumers are able to contribute (ideas, feedback, development) to building innovative solutions on top of the digital platforms in the ecosystem (smart metering platforms, HEMS platforms, data platforms etc.). L2 is opened further in Figure 3.

L3: The Digital Layer – ICT infrastructure, Fog computing, Cloud computing and Big data. The digital layer collects, transfers, stores and manages data from various sensors, home automation devices, energy generation equipment (PV, wind), local storage, electric vehicles, smart metering etc. Digital layer can be seen as an Internet of Things (IoT) stack (see e.g. [34]). IoT and digital architectures are already well understood and defined; our model is based on established concepts (see e.g. [37], [38]).

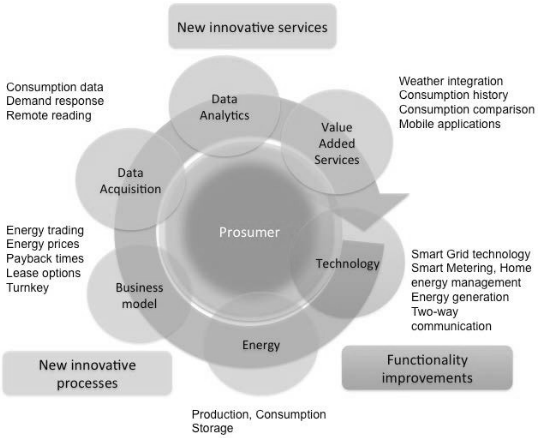

Figure 3. The Value Adding layer

L4: The Energy Layer - Energy production, transmission, distribution, consumption. Key components of the energy process are generation, transmission, distribution and demand. In terms of *physical process*, energy is generated centrally in large scale power plants (nuclear, hydro, coal, thermal) and solar and wind farms or/and de-centrally using distributed energy resources (DER) based on renewable energy resources (RES), such as photovoltaic (PV) or wind. High voltage transmission is managed by infrastructure operated by transmission system operators (TSO) as a monopolistic system. The TSOs are responsible for coordinating the supply and demand for electricity in wholesale market, take care of security of system and also handle cross-border trade between countries. Distribution system operators (DSO) carry the electricity from the transmission to individual consumers. Small-scale distribution is connecting to the grids and amount of bi-directional information and power flow is increasing rapidly. In the new system, DSOs will be in key role in managing the data and will have to deal with e.g. privacy requirements. Demand for energy depends on various aspects in the socio-technical and economic system. Energy demand side management attempts to bring energy supply and demand closer together through various methods including energy efficiency measures, demand response (DR) and dynamic demand. Business process, or *financial process* point of view, the energy market is operated based on wholesale and retail principles.

Table 1. Barriers for prosumption

BARRIER	THEORY
Lack of information on energy production benefits	Missing systemic factor (Porter)
Regulatory barriers that pose limitations, increase complexity and involve bureaucracy	Natural inertia
Resistance from incumbent energy market actors due to concerns over new competition, lack of predictability and controllability, risks associated to the balancing responsibility and investments in legacy infrastructure	Perceived inertia
Lack of incentives due to low electricity prices and unclear business models	Porter's industry forces
Limited openness of technology vendors reducing end user participation in testing, feedback and co-creation of new solutions	Bounded rationality
Economic issues e.g. high investment cost for energy production equipment	Natural inertia
Privacy and security concerns over data usage and energy quality	

Despite the current atmosphere being fertile for citizen participation, there are also obstacles that may slow down the end user participation in the digital energy ecosystem; some of these barriers [39], [40] are listed in Table 1.

4. CONCLUSIONS

We have introduced a propositional prosumer centric Digital Energy Ecosystem Framework (pDEEF) in order to increase comprehension on prosumer role in the future energy ecosystem. The framework was built based on deducting theoretical premises for the systemic nature of energy ecosystem and will require further validation through empirical testing. Prosumer as participant in the ecosystem value co-creation is currently an under-researched area and further studies in evaluating the innovation aspects of prosumption could help to build better understanding of the value creation potential in the energy ecosystem. Our framework exemplifies the needed multi-disciplinary research combining innovation ecosystem, end user role, complex industry transitions and new technology platforms together. The framework also considers systemic nature of the energy markets as socio-technical change (including multi-stakeholder view) and builds links between different types of processes (energy process, digitalization process, value creation process and human activity) that are all relevant for the ecosystem success.

5. REFERENCES

[1] P. Järventausta, "Smart Grids with large scale implementation of Automatic Meter Reading - Experiences from Finland.," in *the Handbook of Clean Energy Systems*, John Wiley & Sons, Ltd, 2015.

[2] F. W. Geels, "The multi-level perspective on sustainability transitions: Responses to seven criticisms," *Environ. Innov. Soc. Transitions*, vol. 1, no. 1, pp. 24–40, 2011.

[3] K. Kotilainen, S. Mäkinen, P. Järventausta, A. Rautiainen, and J. Markkula, "The role of residential prosumers initiating the energy innovation ecosystem to future flexible energy system.," in *Proceedings or European Energy Markets Conference 2016*, 2016.

[4] M. E. Porter, "How competitive forces shape strategy," *Harv. Bus. Rev.*, no. April-March, pp. 137–144, 1979.

[5] E. R. Freeman, *Strategic Management: A Stakeholder Approach*. 1984.

[6] J. A. Schumpeter, *Capitalism, Socialism and Democracy*. HarperCollins Publishers, New York, USA, 1942.

[7] C. M. Christensen, *The Innovators Dilemma*. HarperCollins, New York, USA, 1997.

[8] R. Metcalfe, "Metcalfe's Law Revisited after 40 Years of Ethernet," *Computer*, vol. 46, no. 12, pp. 26–31, 2013.

[9] G. Dosi, "Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change," *Res. Policy*, vol. 11, no. 3, pp. 147–162, 1982.

[10] F. Hacklin, C. Marxt, and F. Fahmi, "An Evolutionary Perspective on Convergence: Including a Stage Model of Inter-Industry Innovation," *Int. J. Technol.*, vol. 49, no. 1–3, pp. 220–249, 2010.

[11] J.-C. Spender, *Industry Recipes, An Enquiry into Nature and Sources of Managerial Judgement*. ournal of the Operational Research Society, 1989.

[12] C. K. Prahalad and R. A. Bettis, "The Dominant Logic: a New Linkage Between Diversity and Performance," *Strateg. Manag. J.*, vol. 7, no. 6, pp. 485–501, 1986.

[13] P. Rosenzweig, *The Halo Effect*. Free Press, New York, USA, 2007.

[14] J. Moore, *The Death of Competition - Leadership and Strategy in the Age of Business Ecosystems*. Wiley, 1996.

[15] "Digital Ecosystems," *Directorate General Information Society and Media, European Commission*. [Online]. Available: http://www.digital-ecosystems.org.

[16] E. Chang and M. West, "DIGITAL ECOSYSTEMS A NEXT GENERATION OF THE COLLABORATIVE ENVIRONMENT," in *Proceedings of iiWAS2006*, 2006, pp. 3–23.

[17] F. Nachira, P. Dini, and A. Nicolai, "Network of Digital Ecosystems for Europe : Roots , Processes and Perspectives," pp. 5–24.

[18] R. Adner, "Match Your Innovation Strategy Innovation to YourEcosystem," *Harv. Bus. Rev.*, vol. 84, no. 4, pp. 98–107, 2006.

[19] C. Wessner, *Entrepreneurship and the innovation ecosystem policy lessons from the United States*. 2005.

[20] D. S. Oh, F. Phillips, S. Park, and E. Lee, "Innovation ecosystems: A critical examination," *Technovation*, vol. 54, pp. 1–6, 2014.

[21] S. H. Schwartz, "Normative Influences on Altruism.," in *Advances in Experimental Social Psychology*, vol. 10, L. Berkowitz, Ed. Academic Press, New York, 1977, pp. 221–279.

[22] M. Laroche, J. Bergeron, and G. Barbaro-Forleo, "Targeting consumers who are willing to pay more for environmentally friendly products," *J. Consum. Mark.*, vol. 18, no. 6, pp. 503–520, 2001.

[23] T. Hargreaves, "Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change," *J. Consum. Cult.*, vol. 11, no. 1, pp. 79–99, 2011.

[24] J. Burgess and M. Nye, "Re-materialising energy use through transparent monitoring systems," *Energy Policy*, vol. 36, no. 12, pp. 4454–4459, 2008.

[25] S. Darby, "The effectiveness of feedback on energy consumption. A Review for DEFRA of the Literature on Metering, Billing and direct Displays," *Environ. Chang. Inst. Univ. Oxford*, vol. 22, no. April, pp. 1–21, 2006.

[26] E. Enkel, O. Gassmann, and H. Chesbrough, "Open R&D and open innovation: Exploring the phenomenon," *R D Manag.*, vol. 39, no. 4, pp. 311–316, 2009.

[27] J. Howe, "The Rise of Crowdsourcing," *Wired Mag.*, vol. 14, no. 6, pp. 1–5, 2006.

[28] C. K. Prahalad and V. Ramaswamy, "co-Creating Unique Value With Customes," *Strateg. Leadersh.*, p. 32,3, 2004.

[29] E. Von Hippel, "Lead users: a source of novel product concepts.," *Manage. Sci.*, vol. 32, no. 7, pp. 791–805, 1986.

[30] E. Von Hippel, "Democratizing innovation," *Journal für Betriebswirtschaft*, vol. 55, no. 1. p. 63–78., 2005.

[31] M. Weber, R. Hoogma, B. Lane, and J. W. Schot, *Experimenting with sustainable transport innovations: a workbook for strategic Niche management.* Seville/Enschede: Universiteit Twente., 1999.

[32] P. Kristensson, J. Matthing, and N. Johansson, "Key strategies for the successful involvement of customers in the co-creation of new technology-based services," *Int. J. Serv. Ind. Manag.*, vol. 2, no. 2, pp. 49–65, 1991.

[33] M. Pallot, B. Trousse, B. Senach, and D. Scapin, "Living Lab Research Landscape : From User Centred Design and User Experience towards User Cocreation," *Technol. Innov. Manag. Rev.*, vol. 1, pp. 19–25, 2010.

[34] M. Kavis, "Investor's Guide to IoT – Part 1: Understanding The Ecosystem," *Cloud Technology Partners*, 2016. http://www.cloudtp.com/2016/02/25/investors-guide-to-iot-part-1-understanding-the-ecosystem/.

[35] S. Karnouskos, "Demand Side Management via prosumer interactions in a smart city energy marketplace," *IEEE PES Innov. Smart Grid Technol. Conf. Eur.*, pp. 1–7, 2011.

[36] A. J. D. Rathnayaka, V. M. Potdar, and S. J. Kuruppu, "An innovative approach to manage prosumers in Smart Grid," *2011 World Congr. Sustain. Technol.*, pp. 141–146, 2011.

[37] O. Mazhelis and P. Tyrvainen, "A framework for evaluating Internet-of-Things platforms: Application provider viewpoint," *Internet Things (WF-IoT), 2014 IEEE World Forum*, no. February 2011, pp. 147–152, 2014.

[38] J. Gubbi, R. Buyya, and S. Marusic, "Internet of Things (IoT): A Vision , Architectural Elements , and Future Directions," *Futur. Gener. Comput. Syst.*, vol. 29, no. 7, pp. 1645–1660, 2013.

[39] D. Six, W. Fritz, and K. Kessels, "Potential Barriers and Solutions for Active Demand : a Qualitative Analysis," in *i_SUP*, 2010, pp. 1–7.

[40] IEA-RETD, "Residential Prosumers - Drivers and Policy Options (RE-Prosumers)," 2014.

PUBLICATION
III

How consumers prefer to innovate in renewable energy and what they expect to get in return for co-creation.

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How Consumers Prefer to Innovate in Renewable Energy and What They Expect to Get in Return for Co-Creation

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***Abstract*— Traditional energy market is currently in transition towards a more flexible energy system in which energy generation is decentralized and based on renewable energy sources, technical platforms are intelligent, vast amount of data is generated and analyzed, and multiple actors are able to participate in various aspects of the energy process. End user role is evolving from consumer towards a prosumer i.e. a producer and consumer of energy. The energy consumers - and prosumers - are envisaged to become significant actors in the future energy ecosystem, which also enables novel type of innovations and value creation opportunities for variety of stakeholders. This paper explores the consumer drivers behind interests in engaging in renewable energy related value co-creation and investigates what kind of rewards the end users expect to get in return for collaboration. We present empirical findings from an exploratory consumer survey conducted in four European countries.**

Keywords—value co-creation; open innovation; ecosystem; energy; consumer; motivation; rewarding

I. Introduction

Energy industry is in profound transition towards more efficient and more sustainable system. Renewable energy technologies are already in commercial phase. New intelligent power grids (Smart Grids) are being rolled out in most markets in Europe and globally. Solar photovoltaic (PV) equipment prices are dropping and the technology is becoming more efficient. Energy storage systems are also developing and are apt to become available for households. And more and more car manufacturers are launching electric vehicles (EVs). At the same time policy push from macro level continues to incentivize businesses and consumer to adopt environmentally sustainable technologies that can help reducing carbon emissions. Consumer adoption is seen as critical for the energy transition; their role in distributed energy generation based on renewable energy sources (RES) is necessary to make the new Smart Grid based decentralized energy system full-fill its purpose. Consumer participation is also highly important for demand response (DR) to work; DR is a critical utility led process to balance peak – off peak consumption of energy through co-operating with energy consumers. DR participants are currently mostly large scale industrial firms, but in the future also individual households are seen as potential contributors [1],[2],[3]. Adoption of EVs is also important for DR: EV batteries could be charged during off peak demand when energy is cheap and the demand is low and discharged back to the grid when energy demand is high. Many are expecting that consumers will increase energy efficient consumption, start sharing excess energy they have produced in micro-grids, or in virtual communities, and contribute to the ecosystem value creation and innovation activities. So far, however, consumer adoption has been relatively slow: mass-market acceptance of renewable energy technologies is yet to take place in most markets [4].

Our focus in this paper is to explore the energy consumer role in renewable energy technology related value co-creation activities. The paper presents findings from an exploratory consumer survey conducted in four European countries. Our aim is to shed more light on consumers' interest in becoming active participants in value co-creation activities and to find out what they would like to get in return for such collaboration.

II. Theory and Litterature Review

A. *Energy industry transition*

We are interested in consumers who become active participants in the developing energy ecosystem. Briscoe [5] defines *digital business ecosystem* (DBE) as 'distributed adaptive open socio-technical system for business, with properties of self-organization, scalability and sustainability, inspired by biological ecosystems'. Core elements of DBE can be summarized as: decentralized architecture, open source, scalable and robust, ability to self-organize, enable global solutions with local autonomy [6]. DBEs encompass industry convergence and openness that enable variety of different ecosystem actors as well as innovation and value creation among the actors. Characteristics of an innovation ecosystem can include elements like: systemic, digitalization, open innovation, mimetic quality, important role of 'niches', etc. [7]. Calling the innovation ecosystem, a *niche* is a way to look at the innovation ecosystem from a socio-technical point of view; this is a very relevant for energy sector, which is currently in transition. Niches can be are seen as protected places where innovation can take place even though regime structures and incumbent actors try to slow down the change [8]. Energy market transition from centralized system based on fossil fuels towards decentralized and sustainable energy generation is a complex and long-term process that can be described e.g. using a socio-technical

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multilevel framework, or a multilevel perspective (MLP) [9]. In the socio-technical transition, macro environment, or the landscape, is putting pressure on an established regime, in our case the energy regime, to change. Key drivers for the macro level pressure in the energy sector are the climate change and need for better energy efficiency. On the other hand, new technology solutions are being developed and they enable intelligent communication between network elements and thus allow multitude of new type of opportunities for innovation in the energy space. The technology development takes place in the niche level in the socio-technical framework. This developing niche ecosystem around new generation of electricity power grids i.e. the Smart Grid technology, is also posing pressure on the energy regime to change. Some of the other enablers for the change are industry convergence that is bringing new type of actors to the energy field from information and communication technologies (ICT), transportation and building and construction. As new actors are able to enter the energy space, the consumer role is also changing. Prosumer, a consumer that starts to produce energy, is emerging as a new participant in the energy market. Energy production by consumers is becoming feasible due to technology and price developments in the solar PV, energy storages, EVs and the electricity infrastructure (like Smart Grids). Besides energy conservation and production, consumers could potentially also become viable contributors to value co-creation in the future energy ecosystem.

B. New product development (NPD) phases

From a firm's point of view, a new product development (NPD) process, or a stage-gate model [10], includes different phases of innovation ideation, productizing and commercialization; the stages include scoping and business case, development, productizing, demonstration and testing and commercialization. These phases can be roughly grouped into: pre-NPD, development (R&D), demonstration and commercialization. Customer requirements and ideas for new products and services are gathered and product strategies are formed in the pre-NPD phase. Herein also lies the valley of death [11], where resources are divided between projects and some promising concepts get inevitably cut off. Demonstration phase can be seen as a pre-launch in which the products are tested internally or, in some cases, with end customer or business partners (lead users). Commercialization starts with launch and continues throughout the rest of the product life-cycle.

C. Open innovation and co-creation

Traditional way of planning and developing new products and services keeps the locus of innovation activities inside the firm; customers have requirements that need to be taken into consideration and other external stakeholders are considered as suppliers and outsourcing partners. Ecosystem way of thinking is emphasizing innovation with end customers, which can have many benefits: innovation capacity and rate can increase, it is possibly to reduce innovation risks, gain increased quality ideas and accelerated time to market [12]. This type of open innovation can be seen as a pre-requisite for a true innovation ecosystem to develop.

Open innovation covers range of innovation activities that take place with external stakeholders. Chesborough and Appleyard [13], define *open innovation* as: "Openness is defined as the pooling of knowledge for innovative purposes where the contributors have access to the inputs of others and cannot exert exclusive rights over the resultant innovation". Curley [14] proposes twelve *principles for "open innovation 2.0"* including; purpose, meaning that aligned efforts deliver greater value than the sum of the parts; partnering that is based on quadruple helix mode; platform that is integrated, modular, open, and can address security & privacy; possibilities that are not only based on products but also on business models; plan that focus on adoption and scale; enabling users to drive innovation; understanding user needs; prototyping with users; piloting in real world and small scale; scaling up prototypes globally; creating product service systems; and innovation process which is a team effort and agile.

There are many terms that are used in the context of open innovation: co-creation, co-innovation, co-development, crowdsourcing, open source software (OSS) development, user centric innovation, lead user innovation, virtual co-creation etc. *Co-creation* can be seen as a sub-category of open innovation, it is a strategy to get together different actors in order to jointly work towards a desired outcome [15]. *Crowdsourcing* is an example of co-creation activity; it seeks novel ideas from often a large group of people. Crowdsourcing campaigns [16] are often used for idea generation in pre-NPD phase. On the other hand *co-development* means working with a group of experts that have special (technical) skills and expertise and can deliver more focused outcomes [17]; it can mean activities related to software development process to which end users are invited to participate and IPR remains with the initiating company [18]. The term *OSS development* refers to publicly accessible development resources that can be accessed and modified [19]. *Co-innovation* covers ecosystem level innovation activities: different actors together develop a systemic offering, for example a turnkey type of package including products, services, business model, delivery model, and maintenance [20]. *User centric innovation* and *lead user* innovation are also forms of co-creation [21]. Lead users can be defined as individuals with unique characteristics: They have some needs that are ahead of the current market requirements but that can later become mainstream. Potential lead users also are willing to participate in innovation activities to get their needs fulfilled [21]. *Do-it-yourself customers* have special requirements for a product functionality and can be seen as prospective lead users. They are also potentially great partners for co-development and co-innovation. In the energy space, *Living labs* and *Smart City projects* are hosting various forms of co-creation activities.

Co-creation process can include a broad range of activities: collecting user feedback, engaging with lead users in new product ideation or development phase, using toolkits to develop OSS or in virtual development communities, and testing products with end users [22],[23], [15]. There are multiple ways to do for co-creation with energy consumers: crowdsourcing platforms, living labs and smart cities, firm projects, prosumer communities (e.g. micro-grid communities).

End users may assume different *roles in co-creation*: They can be idea generators, co-developers, lead users, testers, product specialists, product promoters, etc. [21], [22] ,[24] [25], [26]. The feasibility of consumer role in co-creation can be linked to required skill levels; it is often necessary to involve users with different skill sets and levels of expertise. Individuals with advanced technical skills are able to contribute to design and development phase. Lead users are also sophisticated users who have good technical abilities, which makes them valuable resources for providing viable product ideas, giving feedback and testing. Consumers without technical expert level skill can be a good source for idea generation, validating business models and suggesting process improvements [27]: Gathering viewpoints from individuals outside of the "professional bubble" can deliver inventive solutions.

D. End user motivations for co-creation

Interest to partake in innovation activities depends on multiple factors including external conditions, individual characteristics, values, beliefs, attitudes and motivations. To simplify the complex human decision-making process, we focus on motivational drivers in this study. Motivations can be divided into intrinsic and extrinsic. Intrinsic motivation means doing something for the sake of the activity which is seen rewarding as itself. Extrinsic motivation is based on a desired material or non-material outcome of an activity [28].

Need for relatedness, competence and autonomy have been found in earlier studies to be the three dominant *intrinsic motivations* [28]; relatedness describes the need for a sense of belonging to a community, competence refers to the need to express one's own capability, and autonomy means the ability to act in line with one's value system and needs. Earlier studies have also discovered a number of intrinsic motivations that can be linked to the three basic needs e.g.: acquiring knowledge [29], interest in technology [30], getting feedback [31], discovering new things [32], fun and enjoyment [33], satisfying curiosity [30], forming peer companionships [27], altruism e.g. related to biospheres value [34] etc.

Extrinsic motivations are connected to expectations of a desired outcome or a consequence of an activity, which is seen as a means to an end [35]. Different types of external motivation can include for instance: reputation or career aspirations [36], monetary compensation, peer recognition [37], influencing product or service functionality. As an example of the latter; do-it-yourself customers or lead users may have an extrinsic needs for a certain product functionality [38].

Co-creation in most cases is a creative process. Intrinsic motivations have been found to be central in creative activities [35]. Fuller [39] summarizes from earlier studies the following motivations as key to interests to engage in co-creation: intrinsic playful task, curiosity, self-efficacy, skill development, information seeking, recognition, community support, making friends, personal needs for product functionality and monetary compensation. The motivations for energy production and taking part in co-creational activities may be related to intrinsically wanting to save the planet for altruistic reasons, socially connect with others, feeling of empowerment, curiosity, interest in technology, positive feedback and learning [40] or to financial rewards and other extrinsic needs like getting better products and solutions for personal use, career aspirations, peer recognition or social status [38].

E. Rewarding participation in co-creation

Despite initial motivation to engage in co-creational activities it is necessary to facilitate the process and provide clear benefits for keeping up the interest. Rewards can be seen as a way to strengthen motivations and keep the interest level of the participants high through-out the project. The incentives are often divided into monetary and non-monetary rewards. Monetary rewards are based on extrinsic motivations and may include cash payments, gifts or discounts (e.g. related to electricity bill). Non-monetary incentives may be related to both intrinsic and extrinsic motivations e.g. reward points, ranking, social comparison, gamification or trophy value.

Individuals are naturally motivated to participate when the outcome will affect them directly. Being part of a process to develop new things offers a sense of autonomy and make the participants feel they are in control, rather than being objects of it. People want to be rewarded for their contributions, but not necessarily with a tangible (e.g. financial) reward. Offering extrinsic incentives can even be counterproductive; studies show that extrinsic rewards can reduce intrinsic motivations [28]. There is also evidence, especially related to virtual co-development communities, that people would be satisfied without monetary rewards and they see engagement as a rewarding experience [41].

III. Research approach

This paper explores evolving end user role in the emerging energy ecosystem. Consumer decision making is a complex phenomenon and it has been studied widely in the pro-environmental context and environmental innovation diffusion research. We do not cover the wide array of underlying reasons for interests in pro-environmental behavior in this paper, but are more interested in what kind of value co-creation activities are the most attractive for consumers and what kind of concrete expectations for returns of such collaboration the participants may have. Our aim is to contribute to knowledge related to understanding the consumer drivers for value co-creation in the energy sector that is going through a major industrial change.

Consumers may become active in various ways around energy: They may get involved in demand response schemes, organize in prosumer communities, share energy in virtual groups, micro-grids or with the power grid, or start engage in innovation activities with other actors. This paper focuses on understanding the role and potential of user centric innovation in the energy sector. The main research questions are:

RQ1: How interested consumers are in different types of co-creation activities related to renewable energy solutions (products and services)?

RQ2: What do they prefer to get in return for engagement in value co-creation?

Answering the research questions is approached by gathering empirical data through a consumer survey.

A. Consumer survey and data gathering

Data was gathered as part of a consumer survey conducted in four European countries; Germany, France, Italy and Switzerland between July – December 2016. The data sample used in this paper was gathered using a questionnaire that included in total 79 questions on different aspects of using renewable energy systems. Altogether, the sample size was 163 respondents (N= 163) and the sample size per country was approximately 30. The questionnaire was translated from English to French, German and Italian with the help of native speakers. This paper assesses subset of the data collected; only 16 questions related to consumer interest in innovation activities are studied in this case. We also limit our analysis at this stage to cross-country level both due to small sample size per country and the limited length of the conference paper.

Data collection was mostly done in public areas where participants were expected to have more time to respond to the questionnaire. In addition, the questionnaire was partially distributed door-to-door to reach households that had RES (solar panels on the roof) in order to ensure that some respondents had access to RES related technology enablers. In both approaches, the response rate was approximately 30 %.

Table I summarizes key demographics that were collected as part of this survey. Demographic information gathered includes the respondent housing type and ownership, age group, education level and income level. In addition, we asked information about energy related technology enablers i.e. if the respondent had an electric vehicle (EV) and/or a renewable energy system (RES) in use or a smart meter installed in their house or apartment. One question was related to the respondents' personal characteristics; the participants were asked to self-evaluate whether they see themselves as "Innovative" or "Traditional" (the latter was explained to represent an opposite for the former in the survey).

TABLE I. SAMPLE INFORMATION

Demographic data and technology availability (% of respondents)			***Innovativeness***	Innovative	65
				Traditional	35
Age Group	18-24	20	***Ownership of housing***	Owner	52
	24 – 40	41		Renter	48
	40-55	13	***Housing type***	House	43
	55-	26		Apartment	57
Income level *(household, € / month)*	<3000	38	***EV owner***	Yes	5
	3000-6000	35		No	95
	>6000	27	***Using RES*** *(YES: solar PV, wind, geothermal, other)*	Yes	36
Educational level	Primary school	7		No	64
	Secondary school	36	***Smart meter installed***	Yes	25
	Bachelor	21		No	50
	Masters	64		Don't know	25

B. Data analysis

To answer the RQ1, first question asked the participants to rate their interest in six different innovation, or co-creation, activities related to renewable energy products and services. Theses survey questions are summarized in Table II. The respondents were asked to rate the statements related to the innovation activities on a Likert style scale, in which: 1 = strongly disagree… 7 = strongly agree. The prompted innovation activities are derived from the theory and literature

TABLE II. INNOVATION ACTIVITIES AND THEIR RELEVANCE IN NPD

How interested would you be in collaborating to develop Renewable Energy products/services (1=strongly disagree … 7= strongly agree)	NPD phase
I would be interested in providing ideas for new product functionalities and services	Pre-NPD
I would be interested in co-development of products and services (e.g. coding, design) together with Renewable Energy product and service companies	R&D
I would be interested in testing products and services (before they come commercially available)	Demonstration
I would be interested in giving feedback on renewable energy related products (panels, meters, etc)	Commercial
I would be interested in giving feedback on Renewable Energy related services (support, automatic energy monitoring, etc.)	Commercial
I would be interested in validating new business models (e.g. as a pilot customer)	Commercial

review: idea generation, co-development, testing new products, giving feedback and validating business models. These activities were associated with various phases of NDP process; pre-NDP, R&D, demonstration and commercial phase.

To answer the RQ2, the survey examined what the respondents would expect in return for collaboration in the earlier specified innovation activities. There respondents were asked to rate ten pre-defined factors using the Likert scale, in which: 1 = not at all important … 7 = very important. The questions prompted the respondents with both monetary and non-monetary incentives three of which were directly related to intrinsic motivations and five to extrinsic motivations. In addition, two questions were related to social motives. Social motives can also be seen as either intrinsic or extrinsic; peer recognition is an extrinsic incentive and peer relationship can be seen as an intrinsic incentive. See Table III for summary of RQ2 related questions and their association with motivation and motivational incentive/reward type.

TABLE III. POTENTIAL COMPENSATIONS FOR CO-CREATION AND THEIR MOTIVATIONAL TYPE

If I collaborate to develop Renewable Energy systems it is important to get in return… (1=not important at all … 7 = very important)	Motivational type	Motive based incentive
Monetary compensation	Extrinsic	Monetary
Gifts & rewards (e.g. gift cards)	Extrinsic	Monetary
Challenges and competitions	Extrinsic	Peer recognition
Career opportunities	Extrinsic	Self-efficacy
Exclusive information on Renewable Energy systems	Extrinsic	Needed information
Recognition of others	Extrinsic	Peer recognition
Sense of belonging to a community	Intrinsic	Need for relatednes
Being part of creating better environmentally sustainable products and services	Intrinsic	Altruistic, biospheric value
Enjoying the process and having fun	Intrinsic	Fun, enjoyment
Learning new things	Intrinsic	Competence

IV. FINDINGS

To answer the RQ1, the research surveyed what way the consumers are interested in co-creating related to renewable energy solutions (RES). The variables were associated with the respondent interest in ideation, testing, giving feedback, validating business models and co-development (see Table II). These activities can be further associated with different phases of NPD process. The results (see Fig. 1) show interest in participating in all prompted activities.

Over 50% of the respondents would be from moderately to very strongly interested in testing products, giving product or service feedback and validating business models. On the other hand, less than half would be interested in co-development or ideation for new products and services. The respondents gave highest ratings (mean = 4.60) to *"I would be interested in testing products and services (before they come commercially available*)" and lowest (mean = 3.80) to "*I would be interested in co-development of products and services (e.g. coding, design) together with Renewable Energy product and service companies*". Testing products before they become commercially available can be associated with being a lead user. Co-development differs from the other innovation activities as it in most cases requires strong interest in technologies and potentially expert level technical skills; fewer individuals are able engage in development and design of new products and services. In terms of relatively lower interest in idea generation, earlier research has found that it is difficult to activate people to participate energy related pilots and campaigns, especially those that require a behavioral change.

Fig. 2 depicts the respondent interest in activities related to different NPD phases; the findings show that activities that are taking place either at the commercial or demonstration phase gained most interest from the respondents. These activities gained 54.5 % and 56.3% favorable scores respectively i.e. the respondents rated the activities between 5 and 7 on Likert scale.

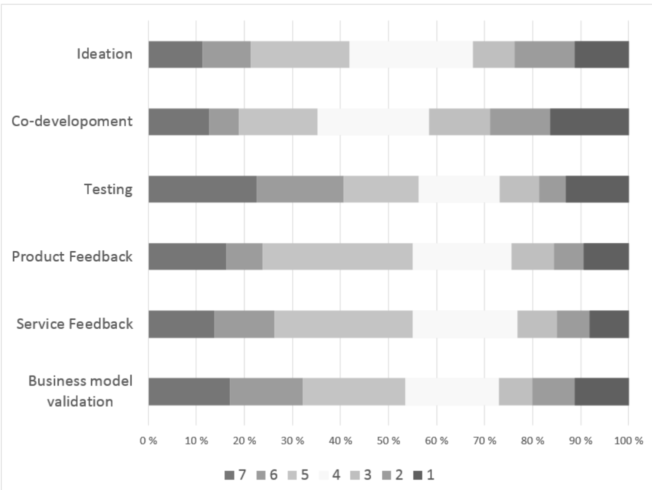

Fig. 1. Rating of interests in innovation activities (7= strongly agree… 1= strongly disagree)

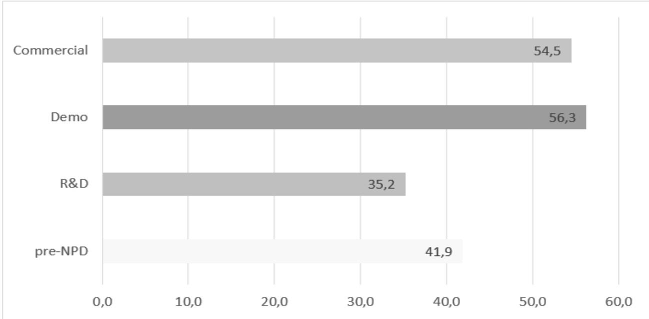

Fig. 2. Interest to participate in innovation activities associated with NPD process phases (% of scores 5-7)

How demographics and availability of technology enablers affected the results? Innovation activities (RQ1) related questions showed statistically significant (95% level) difference (between respondent group) on *smart meter availability* and interest in *giving feedback on products* (p=0.035) and *services* (p=0.016); those who did not know if they had a smart meter installed were less inclined to giving feedback. Similarly, those who identified themselves as "innovative" were keener on *providing ideas for new products* (P=0.004) and *participating in co-development* (=0.012) than those who saw themselves as "traditional" (in this survey portrayed as an opposite to "innovative").

RQ2 focused on what the consumers expect to get in return if they become collaborators in innovation activities related to RES. The questions about incentives were based on extrinsic and intrinsic motivations. The findings are presented in Fig. 3 and Fig. 4.

Generally, the respondents preferred the intrinsic motivation based incentives: *enjoying and having fun,* which 74% rated favorably (scores between 5-7, mean = 5.28*)*, *being part of creating better environment* (82% favorable, mean=5.53), and *learning new things* (82% favorable, mean=5.54). The other incentives that received over 50% favorable scores were: extrinsic motivation based incentive *monetary compensation* (mean = 4.77*)* and social motivation based *sense of belonging to a community* (mean=4.39). Based on the survey, the respondents have lowest interest in receiving *gift cards* (34% favorable,

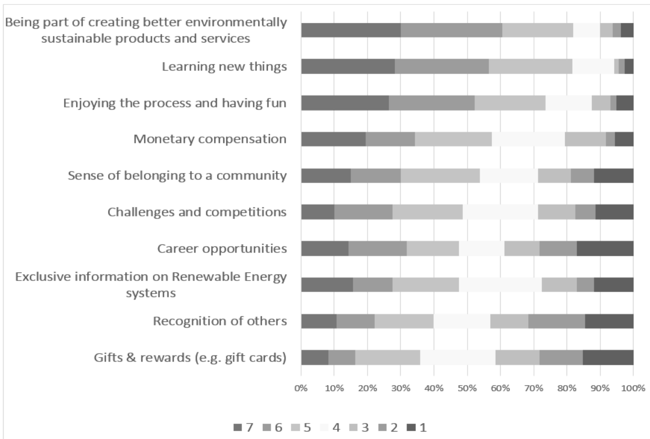

Fig. 3. Rating of the incentives for engaging in innovation activities (7= very important … 1= not at all important)

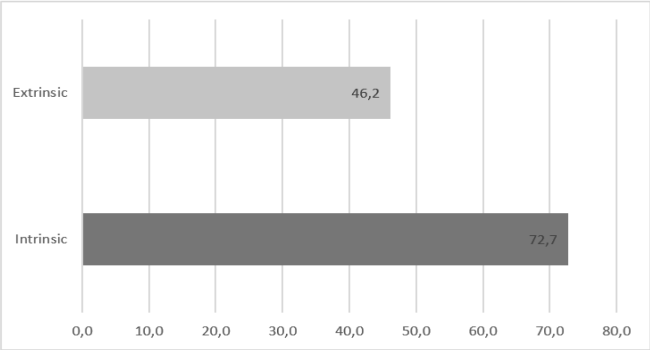

Fig. 4. How much respondents valued rewards related to different motivational drivers (% of scores rated 5-7)

mean = 3.75) and *recognition from others* (40% favorable, mean = 3.84).

The division between favorable rating percentages related to motivation drivers behind the incentives are presented in Fig. 4 above. It noticeably shows that the respondents valued intrinsic rewards (over 70% scored favorably) over extrinsic rewards. This finding is well in line with theory and earlier findings.

There were no statistically significant differences between different demographic groups related to variables for RQ2, except in case of importance of *career opportunities* as seen by different *age groups* ($p=0.001$); the higher the age the lower the importance. This obviously makes sense, as with high age career aspirations are bound to become less relevant, and thus serves also as a control variable for the analysis. Similar association was found for *career opportunities* and *income level* ($p=0.004$); the income group <3000 (euros per month) saw career opportunities as a much more important incentive (mean = 4.86) than the income group >6000 (mean = 3.62). Again, the result is well in line with observations from earlier research.

Housing type is normally an important feature in energy related consumer activity since people living in their own houses have different motives and added control in the decision to invest in renewable energy technologies than people living in apartments. On the other hand, people living in apartments may have more resources to invest in RES as a group. We did not, however, find any significant differences between respondents living in houses or apartments in this study nor between those who owned or didn't own RES; the results would most probably be different if the questions were about other type of activities e.g. related to demand response participation or energy generation using solar PV. There's a broad spectrum of possibilities to participate in energy related innovation activities regardless of direct technology availability.

V. Conclusions

Limitations of the study are related to relatively small sample size and limited number of questions related to the innovation activities in the survey.

The findings confirm that consumers are generally interested in participating in innovation activities related to renewable energy products and services. The results show that consumer interest is inclined towards the later parts of NPD process: demonstration and commercial phases. Co-development requires special technical skills and is therefore understandably proportionally less interesting activity. Slightly more surprising finding is lower interest in idea generation; crowdsourcing campaigns are already widely used by energy utilities and other energy actors and are seen as a way to educate and activate end-users. Nevertheless, earlier research has found that citizens have generally low interest in becoming active in energy related campaigns and pilots.

We also found that the most popular compensations for collaboration were related to learning new things, being part of creating better environment and enjoying and having fun. This validates what earlier research has suggested i.e. that in co-creation, intrinsic rewards are valued more by consumers than extrinsic rewards. Even though monetary and other material investments are popular rewards in consumer targeted campaigns, psychologists have long suggested that using intrinsic incentives is a better way to ensure participation and keep up the interest through the project.

Therefore, we can tentatively propose that rewards based on intrinsic motivations can be successfully used to engage energy consumers and prosumers into co-creation of new products and services for renewable energy ecosystem. Hence, our results suggest ample fruitful directions for future research of prosumer and consumer co-creation activities.

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References

[1] P. Järventausta, "Demand Response - Practical applications and network impacts in Finland," 2015.

[2] S. Annala, S. Viljainen, J. Tuunanen, and S. Honkapuro, "Does Knowledge Contribute to the Acceptance of Demand Response ?," *J. Sustain. Dev. Energy, Water Environ. Syst.*, vol. 1, no. 2, pp. 51–60, 2014.

[3] A. Molderink, S. Member, V. Bakker, M. G. C. Bosman, J. L. Hurink, and G. J. M. Smit, "Management and Control of Domestic Smart Grid Technology," vol. 1, no. 2, pp. 109–119, 2010.

[4] S. O. Negro, F. Alkemade, and M. P. Hekkert, "Why does renewable energy diffuse so slowly? A review of innovation system problems," *Renew. Sustain. Energy Rev.*, vol. 16, no. 6, pp. 3836–3846, 2012.

[5] G. Briscoe, "Complex adaptive digital ecosystems," *Manag. Emergent Digit. Ecosyst.*, 2010.

[6] F. Nachira, P. Dini, and A. Nicolai, "Network of Digital Ecosystems for Europe : Roots , Processes and Perspectives." European Commission, Bruxelles, pp. 5–24, 2007.

[7] D. S. Oh, F. Phillips, S. Park, and E. Lee, "Innovation ecosystems: A critical examination," *Technovation*, vol. 54, pp. 1–6, 2014.

[8] J. Schot and F. W. Geels, "Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy," *Technol. Anal. Strateg. Manag.*, vol. 20, no. 5, pp. 537–554, 2008.

[9] R. Kemp and A. Rip, *Technological change.* Battelle Press, 1998.

[10] R. G. Cooper, "What's Next?: After Stage-Gate," *Res. Manag.*, vol. 57, no. 1, pp. 20–31, 2014.

[11] S. K. Markham, S. J. Ward, L. Aiman-Smith, and A. I. Kingon, "The valley of death as context for role theory in product innovation," *J. Prod. Innov. Manag.*, vol. 27, no. 3, pp. 402–417, 2010.

[12] E. Von Hippel and R. Katz, "Shifting innovation to users via toolkits," *Manage. Sci.*, vol. 48, no. 7, pp. 821–833, 2002.

[13] H. W. Chesbrough and M. M. Appleyard, "Open Innovation and Strategy," vol. 50, pp. 57–76, 2007.

[14] M. Curley, "Twelve Principles for open innovation 2.0," *Nature*, vol. 533, pp. 314–316, 2016.

[15] C. K. Prahalad and V. Ramaswamy, "co-Creating Unique Value With Customes," *Strateg. Leadersh.*, p. 32,3, 2004.

[16] K. J. Boudreau and R. L. Karim, "Using the Crowd asan Innovation Partner," *Harv. Bus. Rev.*, no. April, pp. 1–11, 2013.

[17] M. Bartl, G. Jawecki, and P. Wiengandt, "Co-creation in new product development: conceptual framework and application in the automotive industry," in *Conference Proceedings R&D Management Conference–Information, Imagination and Intelligence, Manchester. Vol 9.*, 2010.

[18] "Definition of customer co-development," *Financial Times Lexicon*. [Online]. Available: http://lexicon.ft.com/Term?term=customer-co_development. [Accessed: 31-May-2016].

[19] "What is open source software?," *Opensource.com*. [Online]. Available: https://opensource.com/resources/what-open-source. [Accessed: 01-Jun-2016].

[20] S. M. Lee, D. L. Olson, and S. Trimi, "Co-innovation: convergenomics, collaboration, and co-creation for organizational values," *Manag. Decis.*, vol. 50, no. 5, pp. 817–831, 2012.

[21] E. Von Hippel, "Lead users: a source of novel product concepts.," *Manage. Sci.*, vol. 32, no. 7, pp. 791–805, 1986.

[22] S. Nambisan, "Virtual Customer Environments : IT-Enabled Customer Co-innovation and Value Co-creation," in *Information technology and product development - annals of information systems*, Springer, 2010, pp. 109–127.

[23] F. Piller and D. Walcher, "Toolkits for Idea Competitions: A Novel Method to Integrate Users in New Product Development," *R&D Manag.*, vol. 36, no. 3, pp. 307–318, 2006.

[24] C. Leadbeater and P. Miller, "Pro-Am Revolution. How enthusiasts are changing our economy and society," *Demos, London*, 2004.

[25] S. J. Bae, P. Gloor, and S. Schnorf, "Detection of Power User Patterns Among High School Students in a Mobile Communication Network," *Appl. Soc. networks Anal.*, 2005.

[26] E. H. Fernley and B. Light, "Unpacking user relations in an emerging ubiquitous computing environment: introducing the bystande," *J. Inf. Technol.*, vol. 23, pp. 163–175, 2008.

[27] D. C. Brabham, "Crowdsourcing the Public Participation Process for Planning Projects," *Plan. Theory*, vol. 8, no. 3, pp. 242–262, 2009.

[28] R. Ryan and E. Deci, "Self-determination theory and the facilitation of intrinsic motivation," *Am. Psychol.*, vol. 55, no. 1, pp. 68–78, 2000.

[29] R. Ryan, C. Rigby, and A. Przybylski, "The motivational pull of video games: A self- determination theory approach.," *Motiv. Emot.*, vol. 30, no. 4, pp. 344–360, 2006.

[30] R. Agarwal and E. Karahanna, "Time flies when you're having fun: Cognitive absorption and beliefs about information technology usage.," *MIS Q.*, vol. 24, no. 4, pp. 665–694, 2000.

[31] J. Reeve, "The interest-enjoyment distinction in intrinsic motivation," *Motiv. Emot.*, vol. 13, no. 2, pp. 83–103, 1989.

[32] N. Yee, "Motivations for play in online games.," *Cyberpsychology Behav.*, vol. 9, no. 6, pp. 772–775, 2006.

[33] P. B. Lowry, J. E. Gaskin, N. W. Twyman, B. Hammer, and T. L. Roberts, "Taking ' Fun and Games ' Seriously : Proposing the Hedonic-Motivation System Adoption Model (HMSAM)," *J. Assoc. Inf. Syst.*, vol. 14, no. 11, pp. 617–671, 2013.

[34] T. Dietz, A. Fitzgerald, and R. Shwom, "Environmental Values," *Annu. Rev. Environ. Resour.*, vol. 30, no. 1, pp. 335–372, 2005.

[35] T. M. Amabile, *Creativity in context: Update to the social psychology of creativity.* Westview press, 1996.

[36] F. D. Davis, R. P. Baggozzi, and P. R. Warshaw, "Extrinsic and intrinsic motivation to use computers in the workplace.," *J. Appl. Soc. Psychol.*, vol. 22, pp. 1111–1132, 1992.

[37] K. R. Lakhani and R. G. Wolf, "Why Hackers Do What They Do : Understanding Motivation and Effort in Free / Open Source Software Projects 1 By," *Perspect. Free Open Source Softw.*, pp. 1–27, 2005.

[38] M. Wolf and S. McQuitty, "Understanding the do-it-yourself consumer: DIY motivations and outcomes," *AMS Rev.*, vol. 1, pp. 154–170, 2011.

[39] J. Füller, "Refining Virtual Co-Creation from a Consumer Perspective.," *Calif. Manage. Rev.*, vol. 52, no. 2, pp. 98–122, 2010.

[40] S. Nyborg and I. Ropke, "Constructing users in the smart grid—insights from the Danish eFlex project.," *Energy Effic.*, vol. 6, no. 4, pp. 655–670, 2013.

[41] J. Fuller, "Why Consumers Engage in Virtual New Product Developments Initiated By Producers," *Adv. Consum. Res.*, vol. 33, pp. 639–646, 2006.

PUBLICATION IV

Exploring the microfoundations of end-user interests toward co-creating renewable energy technology innovations

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Exploring the microfoundations of end-user interests toward co-creating renewable energy technology innovations

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ABSTRACT

Energy market transition, which is enabled by new affordable energy technologies and digitalization, opens novel opportunities for developing innovative energy solutions. These new technologies facilitate energy consumers to become local energy prosumers i.e. consumers and producers of energy using renewable energy sources. Hence, a central question for innovating new solutions emerges: how energy consumers and prosumers would engage in co-creating value and novel solutions with industry players? This article explores the microfoundations of energy consumers' and prosumers' interest to participate in co-creation activities with energy industry actors. Using survey data from five European countries and by applying variance-based structural equation modeling, we find that rewards and personal characteristics influence the interest to engage in co-creation activities. Specifically, the microfoundations of the interest are built upon the need for improvements, the intrinsic rewards, and the personal adopter characteristics. Additionally, we find differing microfoundations of interest for energy consumers and prosumers. We further discuss managerial and theoretical implications of our findings and highlight avenues for future research.

1. Introduction

The need for climate change mitigation is forcing the energy system to undergo a profound transformation from a centralized structure based on large power plants toward a system that increasingly relies on distributed generation (DG) and renewable energy sources (RES). Digitalization, electrification, increased system flexibility, decentralization and democratization, are key enablers for this transition toward low carbon energy systems required for cleaner production (Astarloa et al., 2017; IRENA, 2018).

As industries, for example information and communication technology (ICT), transportation, and buildings, around the energy system gradually converge, new actors emerge in the energy sector. The role of energy consumers is also changing, because individual households now have access to affordable renewable energy technologies (RET), thereby enabling them to self-produce and consume energy, store energy, sell and share energy, and actively participate in energy processes (Perković et al., 2018). Consequently, governments and regulators have recognized the need to address and better define the role of these energy consumers that are becoming prosumers, that is producers and consumers of energy (Kotilainen and Saari, 2018). The European Commission (EC) (2016) acknowledges, for example, small-scale energy prosumers as "active consumers" by defining them as "a customer or a group of jointly acting customers who consume, store or sell electricity generated on their premises, including through aggregators, or participate in demand response or energy efficiency schemes provided that these activities do not constitute their primary commercial or professional activity."

Expectations are also building up for innovative technology solutions that could accelerate the low-carbon transition (IRENA, 2018). Sustainable innovations — also called green innovations, environmental innovations, or eco-innovations — are aimed at reducing all negative impacts, whether economic, social, and ecological, on the environment (Schiederig et al., 2012). Their

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importance is widely acknowledged: The European Union tracks the status of eco-innovations as part of the sustainable development indicators (Szopik-depczy et al., 2018). The spectrum of sustainable innovations is broad and our present inquiry focuses particularly on energy related innovations, which have traditionally been mega projects that require large upfront investments governed by tight regulations (Bryant et al., 2018). The entry threshold for new actors, especially for those with fewer resources, has been particularly high in the energy sector. With the introduction of RET, digitalization, and new regulations, the avenues are opening for smaller scale energy innovations and new business models. For example, data-driven services and applications are needed to take full advantage of smart power grids that can transfer data bidirectionally and in real time. The development of these services requires a systemic approach and input from various stakeholders, including the end users of energy (Bigerna et al., 2016; Hyysalo et al., 2017). Recent research suggests that the different stakeholders must find ways to co-operate in order to realize the full-blown potential of the sustainable innovations (Aquilani et al., 2018; Kruger et al., 2018).

This leads to the question of how to motivate energy end users to become active in the innovation co-creation. While general research around user-centric innovations have been active over the past decade, recent studies call for more research of the factors influencing the antecedents, creation, development, and diffusion of user co-created innovations (e.g., Korjonen-Kuusipuro et al., 2017). Alves et al. (2016) suggest further research on understanding what strategies are needed to support consumers' value-creation processes. RET diffusion is increasing, but Heiskanen and Matschoss (2017) state that it is still necessary to improve the understanding of how household renewable energy systems are diffused across Europe. End-user and RET-focused energy innovation research still is limited. Hyysalo et al. (2013) studied end-user innovations related to heat-pump and wood-pellet burning systems in Finland and suggest that the role of inventive users is important in both the technical evaluation and market creation for new technologies. Hyysalo et al. (2017) also explored the diffusion of consumer innovation in sustainable energy technologies and state that “prosumers create new technology solutions, collaborate with other consumers, and share their ideas, knowledge and inventions with peers in online communities they have formed.” Kotilainen et al. (2018) analyzed how consumers and prosumers collaborate in renewable energy technology innovations and discovered a generally high level of interest, but that this interest is more focused on the later phases of the new product development process (NPD), namely the demonstration and commercialization phases. This paper builds on the results of this earlier research by further investigating the microfoundations behind these interests to collaborate. Our research questions are: 1) What are the microfoundations of end-user interest to collaborate in the co-creation of RET innovations? 2) How do energy consumers and prosumers differ when it comes to their interest to collaborate?

We approach this topic by developing a conceptual framework for the microfoundations of interests to collaborate in RET. We test the model with empirical consumer survey data and analyze it with the variance-based structural equation modeling method by using the SmartPLS 3 analytics tool (Ringle et al., 2015).

2. Theoretical background

2.1. Concepts of open innovation, user-centric innovation, and co-creation

Over the past decades, innovating has evolved profoundly from the traditional emphasis on internal company process toward a more open and externally focused approach. Open innovation refers to innovating co-operatively with external stakeholders; Chesbrough (2003) defined it as “a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology”. Co-innovation is stretching the openness and stakeholder involvement even further (Lee et al., 2012): It is an ecosystem-wide activity that involves multiple stakeholders that collaborate toward a shared goal, while simultaneously competing with one another (Nachira et al., 2007). Co-creation means bringing together different actors to jointly produce an outcome that has value for everyone involved (Prahalad and Ramaswamy, 2004). Collaborating and co-creating with end users is also referred to as user-centric innovation or lead user innovation (von Hippel, 1986). Earlier research suggested that user-centric innovations can be turned into successful products and services (von Hippel, 2005). Co-creation can either be company facilitated or individually initiated (Nielsen et al., 2016). The following sections examine the features of these two approaches.

2.1.1. Company facilitated co-creation

Co-creation with end users can encompass a range of activities, for example, collecting user feedback, lead user engagement, open source software (OSS) development, and product testing (Nambisan, 2010). The engagement with end users may stretch over the entire NPD process, which can roughly be grouped into pre-NPD, development, demonstrations, and commercialization phases (Cooper, 2014).

In the pre-NPD phase, the company's focus is on identifying new ideas and opportunities, customer requirements, as well as developing concepts and prototypes. Sourcing ideas from end users is nowadays often done with crowdsourcing campaigns supported by digital platforms that offer low threshold opportunities to participate. Yet, earlier research has found that the interest level of participants may be relatively low for the ideation of novel RET solutions (Kotilainen et al., 2018). The development phase requires that end users have an interest in technology and, in most cases, also certain technical skills, such as software programming that uses OSS. The demonstration phase offers opportunities for lead users to test products before they become commercially available. Lead user innovations have been studied, for example, by von Hippel (1986). Currently, many innovative energy solutions are created and tested in living labs where consumers are observed when they actually use these solutions (Ballon et al., 2018; Heiskanen et al., 2018; Leminen et al., 2017). Living labs are a good example of strategic niche management (Schot and Geels, 2008) that links innovations to the socio-technical transition. Such protected spaces nurture innovations, thereby enabling them to develop before facing competition from incumbent technologies.

The innovations that make it to the commercialization phase must deal with the challenge of convincing customers to adopt them successfully. According to the diffusion of innovations (DOI) theory (Rogers, 1995), the innovators and the early adopters are generally less price sensitive and more technologically savvy, as well as risk-tolerant, than the later categories of early and late majority mass-market users. These features make the innovators and early adopters more willing to test unmatured products, whereas the later adopter groups expect high quality and value for their investment.

2.1.2. Independently initiated co-creation

Reasons why users want to innovate independently may arise from the lack of product availability, the need for improved functionality, inferior quality, or the need for customization. Do-it-yourself (DIY) customers are a group of users that has been studied in this context (Cloutier et al., 2018; Nesti, 2018). DIY customers often have technical know-how and participate in discussion forums, OSS, or virtual co-creation environments to ideate, develop, and modify products or to provide suppliers with feedback.

The nature of independently initiated co-creation is often systemic (Nielsen et al., 2016). Energy communities emerge as the number of energy prosumers grows, including local micro-grid communities and virtual communities, such as peer-to-peer groups or even virtual power plants (VPP) that use wind or solar technologies (Mamounakis et al., 2015; Morstyn et al., 2018; Pasetti et al., 2018). Innovations that grow from local community experiments can result in solutions, which combine several aspects of the community energy solution. These grass roots innovations emerge as a bottom-up way of contributing to the creation of sustainable systems (Hossain, 2016).

2.2. *Understanding the microfoundations of consumer co-creation interests*

The term "microfoundations" has been used in social sciences and economics with multiple definitions (e.g., Barney and Felin, 2013). Here, microfoundations refer to the drivers of individuals' interests for co-creation and collaboration. To explore the microfoundations, it is necessary to understand theories related to consumer behavior, especially Fishbein and Ajzen's (Fishbein and Ajzen, 1975) theory of reasoned action (TRA) and Ajzen's (Ajzen, 1985) theory of planned behavior. The key elements of these theories are the values, beliefs, attitudes, and norms that affect consumer intentions and behavior. Variations of these theories can be found in a multitude of studies that investigate sustainable consumer behavior related to energy consumption and using RET. For example, environmental attitudes are allegedly a predictor of pro-environmental behavior (Poortinga et al., 2004; Steg et al., 2005; Stern, 2000). The Motivation-Opportunity-Ability-behavior (MOAB) model proposes that motivations, opportunities, and abilities act as the antecedents of behavior. MOAB is a framework that "conceptualizes the determinants of consumer behavior in relation to sustainability" (Nielsen et al., 2016). This paper focuses on MOAB's motivation and ability premises, because the opportunities for participation are mostly related to macro-level enabling elements (processes, platforms, etc.).

Drawing from earlier research in this domain, we identified four significant elements that are the microfoundations of individual consumers' interest in RET innovation collaboration: personal characteristics, environmental attitudes, needs for improvement, and available rewards. Our framework for the microfoundations is summarized in Fig. 1.

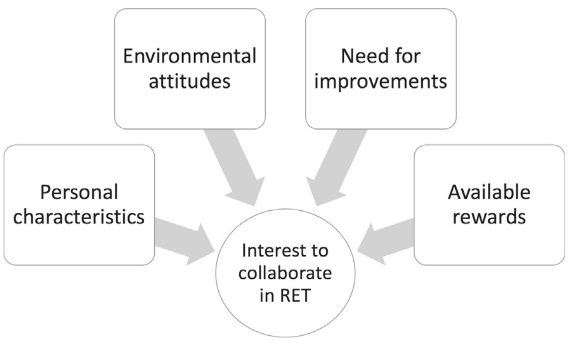

Fig. 1. Conceptual model to address the microfoundations of end user interests in RET collaboration.

2.2.1. *Personal characteristics*

Participation in the co-creation requires various levels of technical skills or tolerance for unmatured products with potential defects. The DOI theory (Rogers, 1995) identifies several groups of innovation adopters with distinctive characteristics. For example, an interest in technology and early adopter characteristics are related to an interest in acting as a lead user, giving product feedback, and participating in co-development activities (Rogers, 1995; von Hippel, 2005). On the other hand, products' ease of use, as well as seeking recommendations and support from others, are associated with the later adopter categories and these late adopters' actions are based on these antecedents. Similarly, late mass-market users are risk-averse and price sensitive (Rogers, 1995; Toft and Thogersen, 2014), which also may influence late adopters' collaboration behavior. Our first hypotheses are:

H1a: Personal characteristics have a positive impact on the interest to collaborate when it comes to value co-creation;
H1b: Early adopter characteristics have a positive impact on the interest to collaborate when it comes to value co-creation; and
H1c: Late adopter characteristics have a positive impact on the interest to collaborate when it comes to value co-creation.

2.2.2. *Pro-environmental attitudes*

Pro-environmental values have been found to be a key reason for adopting sustainable innovations (Chen, 2014; Clark et al., 2003; Oreg S and Katz-Gerro T, 2006; Stern, 2005) and the same logic could be applied to the collaboration interests. Green users exhibit a strong interest in adopting environmental innovations (Akehurst et al., 2012). Certain green users are early adopters who are willing to act as sponsors of new, sustainable innovations (Nygren et al., 2015). However, certain studies point out that pro-environmental attitudes do not necessarily lead to pro-environmental behavior (Kennedy et al., 2009; Kollmuss and Agyeman, 2002). Since the results for the linkage between pro-environmental attitudes and behavior are inconclusive, it is worthwhile to study this area further. We therefore hypothesize that:

H2: Environmental attitudes have a positive impact on the interest to collaborate when it comes to value co-creation.

2.2.3. *Need for improvements*

We already established that the need for improvement can increase the interest to collaborate. This could in practice take place via providing different types of feedback to a supplier. Providing feedback is considered as a form of collaboration (Kumar et al., 2010). Giving positive feedback is a way of ensuring that the supplier maintains the current level of offering. The motivation for providing negative feedback differs from the motivation for giving positive feedback, because it usually refers to a reclamation, a return, or a money-back claim (Söderlund, 1998). Negative feedback is usually set off by a bad experience or a defective product (Ofir and Simonson, 2001). The need for product functionality improvements may lead to activity that is intended to improve the offering, either through giving feedback to the supplier or DIY activities. Our third set of hypotheses is therefore:

H3a: The need for improvements has a positive impact on the interest to collaborate when it comes to value co-creation;
H3b: Dissatisfaction has a positive impact on the interest to collaborate when it comes to value co-creation;
H3c: Satisfaction has a positive impact on the interest to collaborate when it comes to value co-creation; and

H3d: The intention to improve feedback has a positive impact on the interest to collaborate when it comes to value co-creation.

2.2.4. Available rewards

Earlier research (e.g., Antikainen and Vaataja, 2010; Füller, 2010) concluded that co-creation participants want clear benefits and that different types of rewards motivate the end users. Self-determination theory (Ryan and Deci, 2000) distinguishes between two types of motivation – intrinsic and extrinsic – and identify three core types of intrinsic motivations: self-efficacy, autonomy, and the need for relatedness. Research has identified several intrinsic motivations linked to these basic needs: learning new things (Wolf and McQuitty, 2011), interest in new technologies (Amabile, 1996), obtaining knowledge (Ryan and Deci, 2000), receiving feedback (Reeve and Craig, 1989), curiosity (Agarwal and Karahanna, 2014), fun and enjoyment (Lowry et al., 2013), peer relations (Butler and Nisan, 1986), and valuing the biosphere. Contrary to intrinsic motivations, extrinsic motivations are linked to expectations of a favorable outcome, for example: reputation or career aspirations (Davis et al., 1992), monetary compensation, peer recognition (Lakhani and Wolf, 2005), and influencing product or service functionality due to need for product improvement (Wolf and McQuitty, 2011).

Aspects like learning, enjoyment, fun, a sense of belonging, career advancement, money, gifts, etc. have been found to influence user interest in co-creation (Adler, 2011; Amabile, 1996; Antikainen and Vaataja, 2010; Frederiks et al., 2015; Füller, 2010; Hossain, 2012; von Hippel, 2005). Certain studies have also indicated that intrinsic rewards are better motivators for co-creation than extrinsic rewards (Amabile, 1996; Füller, 2010). Füller (2010) identifies ten typical motivations for co-creation: financial compensation, personal needs, recognition, skill development, seeking information, community support, making friends, self-efficacy, curiosity, and an intrinsic playful task.

We hypothesize that available rewards form the fourth basis for the microfoundations of collaboration:

H4a: Available rewards have a positive impact on the interest to collaborate when it comes to value co-creation;
H4b: Intrinsic rewards have a positive impact on the interest to collaborate when it comes to value co-creation; and
H4c: Extrinsic rewards have a positive impact on the interest to collaborate in value co-creation.

3. Analysis and results

3.1. Data and method

To test the hypotheses and the underlying model shown in Fig. 1, we use variance-based structural equation modeling (the partial least squares approach, PLS-SEM), which is widely used in social science disciplines such as operations management (Peng and Lai, 2012), supply chain management (Kaufmann and Gaeckler, 2015), and information systems research (Hair et al., 2017a, b)). PLS-SEM is useful for success factor research (Albers, 2010) to explain and predict the key target construct of interest (Sarstedt et al., 2017).

To obtain the data for the analysis, we designed an exploratory consumer survey with a heterogeneous sample that includes prosumers and consumers with different cultural backgrounds. In the survey, we measured the items by using a Likert scale with response options from 1 to 7. The measurement model consists of the survey question items presented in Appendix A. The questionnaire was tested with a sample group and, based on the results, small amendments were made before conducting the survey in Germany, Finland, France, Italy, and Switzerland. The total number of respondents is 197 (N) of which 122 are consumers, and 75 prosumers who confirmed that they had access to RET for energy production (e.g solar photovoltaic) at their place of residence. Appendix B shows the survey respondents' demographic information.

3.2. Assessment of the measurement model

We conducted a variance-based SEM analysis by means of PLS using the SmartPLS 3 software (Ringle et al., 2015). Fig. 2 and Tables 1 and 2 show the results of our model. The results assessment considers two stages: First, we assessed the measurement model and then the structural model (Chin, 2010; Sarstedt et al., 2017). Our measurement model is a second-order formative model with two first-order constructs that incorporate a formative measurement model (*intrinsic rewards* and *extrinsic rewards* categorized under *available rewards*) and six first-order constructs with reflective measurement models (the following are categorized under *need for improvements: satisfaction, dissatisfaction*, and *intention to improve*; the following are categorized under *personal characteristics: early adopter* and *late adopter*; and *environmental attitudes*). We assessed the quality of the reflective measurement models by checking the standardized outer factor loadings of the items in the *personal characteristics*, *need for improvement*, and *environmental attitudes* constructs. The outer loadings are close to the recommended threshold value of 0.70 ($p < 0.05$). The constructs mainly have loadings above the recommended threshold value of 0.70 (see Table 3; Hair et al., 2017a, b).

In a formative measurement model, the indicators can be

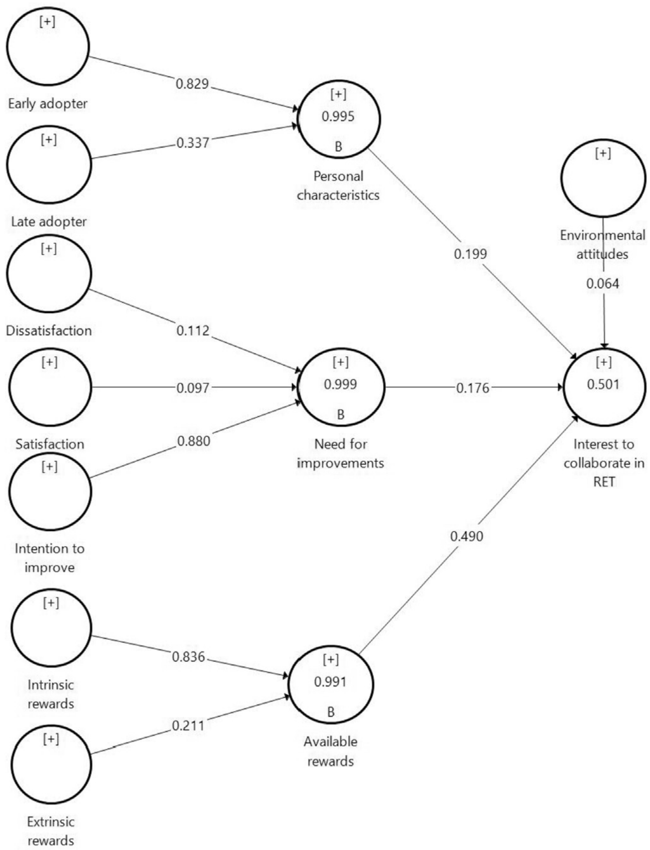

Fig. 2. Structural model with path coefficients.

Table 1
Measurement model results.

	Indicator	Outer loadings	Outer weights	Outer loadings/weights: 95% bias-corrected confidence interval	Significant ($p < 0.05$)?	VIF of formative measurement model indicators
Reflective						
Need for improvements						
Dissatisfaction	AP1	0.90		[0.86; 0.94]	Yes	
	AP2	0.91		[0.85; 0.93]	Yes	
Intention to improve	AP3	0.90		[0.87; 0.92]	Yes	
	AP4	0.90		[0.86; 0.92]	Yes	
Satisfaction	AP5	0.95		[0.93; 0.97]	Yes	
	AP6	0.95		[0.92; 0.97]	Yes	
Interest to collaborate	EIRe1	0.85		[0.75; 0.89]	Yes	
	EIRe2	0.86		[0.82; 0.89]	Yes	
	EIRe3	0.83		[0.78; 0.88]	Yes	
	EIRe4	0.88		[0.84; 0.92]	Yes	
	EIRe5	0.86		[0.83; 0.89]	Yes	
	EIRe6	0.82		[0.77; 0.86]	Yes	
Personal characteristics						
Early adopter	InvDDI1	0.77		[0.72; 0.83]	Yes	
	InvDDI2	0.74		[0.64; 0.81]	Yes	
	InvDDI3	0.72		[0.60; 0.79]	Yes	
	InvDDI4	0.79		[0.73; 0.83]	Yes	
Late adopter	InvDDI5	0.67		[0.43; 0.82]	Yes	
	InvDDI6	0.71		[0.53; 0.84]	Yes	
	InvDDI7	0.76		[0.65; 0.89]	Yes	
	InvDDI8	0.60		[0.36; 0.73]	Yes	
Environmental attitude	InvDGV1	0.85		[0.73; 0.91]	Yes	
	InvDGV2	0.82		[0.68; 0.88]	Yes	
	InvDGV4	0.65		[0.39; 0.75]	Yes	
	InvDGV5	0.74		[0.59; 0.86]	Yes	
Formative						
Available rewards						
Intrinsic rewards						
	Mot3		0.18	[-0.02; 0.41]	No	1.73
	Mot4		0.45	[0.24; 0.66]	Yes	1.31
	Mot7		0.39	[0.16; 0.63]	Yes	2.29
	Mot9		0.33	[0.09; 0.58]	Yes	1.82
	Mot10		0.08	[-0.18; 0.32]	No	1.54
Extrinsic rewards						
	Mot1		−0.01	[-0.22; 0.19]	No	1.38
	Mot2		0.09	[-0.10; 0.30]	No	1.36
	Mot5		0.34	[0.11; 0.55]	Yes	1.52
	Mot6		0.53	[0.30; 0.72]	Yes	1.50
	Mot8		0.38	[0.15; 0.61]	Yes	2.54

insignificant, because of multicollinearity. Thus, it is important to verify the variance inflation factor (VIF), which is a measure of collinearity used in formative measurement models (Hair et al., 2011). We checked that the VIF values of the constructs that measure available awards ensure an absence of collinearity problem (Hair et al., 2017a, b). The VIF values of all indicators should be below 5 (Hair et al., 2011). In our model, the VIF values for the indicators categorized under *extrinsic rewards* and *intrinsic rewards* are all below 3, thereby confirming that there is no collinearity between the variables (Table 1). The results indicate that the indicator results are mainly significant and are relevant for the model.

In addition, we assessed the outer weights to evaluate the composite indicators' relevance in the model. The bias-corrected and accelerated bootstrapping of 5,000 samples in SmartPLS resulted in 95% bias-corrected confidence intervals for the outer weights, which enables assessing the significance of the results at the $p < 0.05$ significance level.

The Cronbach's alpha values of the constructs with first-level reflective measurement models are greater than 0.70 in respect of all the variables, apart from the *late adopter* construct whose value is 0.63. The rho_A values of our model's constructs are very close to Cronbach's alpha, with the same threshold values applying to them as well. The more liberal composite reliability (CR) to assess the internal consistency of a PLS-SEM model's constructs indicates that the values of our reflective measurement model fall between satisfactory levels of 0.70 and 0.90 (J. F. J. Hair et al., 2017a, b). The average variance extracted (AVE) is used to evaluate the convergent validity of the reflective constructs in the first-level constructs. An AVE value of 0.50 or higher indicates that the construct explains more than half of its indicators' variance (Sarstedt et al., 2017). The model's AVE values are mostly above the recommended threshold 0.50, with only the *personal characteristics* constructs having AVE values slightly below the recommended ones.

Furthermore, we also support the discriminant validity of the first-order constructs in the model by using the heterotrait-monotrait correlations (HTMT) (Henseler et al., 2015). The threshold value for HTMT is less than 0.90. The greatest HTMT value in our model is 0.72 (*Intention to improve -> Satisfaction*), which indicates that the constructs' discriminant validity is acceptable and that the measurement model's quality is satisfactory.

3.3. Assessment of the structural model

The structural model estimation provides the path coefficients

Table 2
Path coefficients (β), confidence intervals, and support for the hypotheses.

Complete dataset	Path	β	95% bias-corrected confidence interval	Significant ($p < 0.05$)?
H1a: Personal characteristics have a positive impact on adopters' interest to collaborate when it comes to value co-creation	Personal characteristics - > Interest to collaborate	0.20	[0.07; 0.33]	Yes
H1b: Early adopter characteristics have a positive impact on interest to collaborate when it comes to value co-creation	Early adopter - > Personal characteristics	0.83	[0.61; 1.00]	Yes
H1c: Late adopter characteristics have a positive impact on interest to collaborate when it comes to value co-creation	Late adopter - > Personal characteristics	0.34	[0.01; 0.60]	Yes
H2: Environmental attitudes have a positive impact on interest to collaborate when it comes to value co-creation	Environmental attitudes - > Interest to collaborate	0.06	[-0.04; 0.16]	No
H3a: Need for improvements have a positive impact on interest to collaborate when it comes to value co-creation	Need for improvements - > Interest to collaborate	0.18	[0.04; 0.30]	Yes
H3b: Dissatisfaction has a positive impact on interest to collaborate when it comes to value co-creation	Dissatisfaction - > Need for improvements	0.11	[-0.27; 0.51]	No
H3c: Satisfaction has a positive impact on interest to collaborate when it comes to value co-creation	Satisfaction - > Need for improvements	0.10	[-0.26; 0.45]	No
H3d: The intention to improve has a positive impact on interest to collaborate when it comes to value co-creation	Intention to improve - > Need for improvements	0.88	[0.58; 1.12]	Yes
H4a: Available rewards have a positive impact on interest to collaborate when it comes to value co-creation	Available rewards - > Interest to collaborate	0.49	[0.35; 0.58]	Yes
H4b: Intrinsic rewards have a positive impact on interest to collaborate when it comes to value co-creation	Intrinsic rewards - > Available rewards	0.84	[0.56; 1.02]	Yes
H4c: Extrinsic rewards have a positive impact on interest to collaborate when it comes to value co-creation	Extrinsic rewards - > Available rewards	0.21	[-0.03; 0.53]	No

Table 3
PLSpredict results.

Interest to collaborate	$Q^2_{predict}$	PLS-SEM[a]		Linear model benchmark[a]	
		RMSE	MAE	RMSE	MAE
EIRe1	0.27	**1.50**	**1.20**	1.68	1.31
EIRe2	0.29	**1.43**	**1.16**	1.57	1.24
EIRe3	0.27	**1.60**	**1.29**	1.69	1.35
EIRe4	0.35	**1.46**	**1.17**	1.55	1.25
EIRe5	0.37	**1.50**	**1.17**	1.53	1.22
EIRe6	0.26	1.68	1.34	**1.67**	**1.29**

[a] When comparing the PLS-SEM results against the linear model benchmark, the numbers in bold indicate where the prediction error is smaller.

and R^2 values shown in Fig. 2. In order to assess the results, we used the bootstrapping method to test the strength and significance of the hypothesized path coefficients. The bootstrapping method in SmartPLS was run with 5,000 samples. The hypotheses are supported, as shown in Table 2.

The path coefficients in the analyzed model explain approximately 50% of the variance linked to the key target construct *interest to collaborate* (i.e., $R^2 = 0.501$). In addition to assessing the R^2, we checked the effect size (f^2) to establish if the R^2 values change if a construct is omitted from the model. The threshold for a small effect is 0.02, for a medium one 0.15, and for a large one 0.35 (J. F. J. Hair et al., 2017a, b). The effect of omitting the construct would be small for *need for improvements* (f^2; 0.05) and for *personal characteristics* (f^2; 0.06), but large (f^2; 0.39) for *available rewards*; however, omitting *Environmental attitudes* would have no effect (f^2; 0.01).

Finally, we apply the PLSpredict by Shmueli et al. (2016) procedure to assess the out-of-sample predictive quality of the model for the key target construct *interest to collaborate*. All indicators have a positive $Q^2_{predict}$ value (Table 3). Moreover, for five out of six indicators, the PLS-SEM results have a smaller prediction error compared with the linear model benchmark. Hence, we conclude the model has a medium to high predictive power (Shmueli et al., 2019).

4. Discussion

Our results find significant ($p < 0.05$) support for most of the hypotheses. As shown in Fig. 2, the positive coefficients confirm the influence of *available rewards* (0.49), *personal characteristics* (0.2), and *need for improvement* (0.18) on *interest to collaborate*. In addition, we find that *intention to improve* dominates the influence on *need for improvements* (0.88), as is also the case with the influence of *intrinsic rewards* on *available rewards* (0.84). Furthermore, *personal characteristics* significantly influence (0.83) the *early adopter* characteristics and therefore they have a greater influence than late adopter type (0.34). However, *environmental attitudes* do not have a statistically significant influence on *interest to collaborate* (H2). Likewise, H3b and H3c are not supported, thereby indicating that giving feedback due to product satisfaction or dissatisfaction are not indicators of co-creation interests. Furthermore, rewards triggered by extrinsic motivations do not contribute to the co-creation interests.

In order to analyze the areas that need to be primarily improved to promote energy consumers' interest to collaborate, we ran an importance-performance map analysis (IPMA) with the *interest to collaborate* construct as the endogenous target variable. This analysis extends the path coefficient results with a dimension that considers the average values of the latent variables' scores, that is, their performance. IPMA also calculates the exogenous variables that have importance or total effects by explaining the endogenous target construct's variance (Ringle and Sarstedt, 2016). This method highlights the determinants with high importance effects, but low performance, and shows what researchers need to focus on when aiming to improve the constructs' performance. The IPMA results indicate clear differences in the determinants' group-specific importance and performance regarding consumers and prosumers (Figs. 3 and 4).

Environmental attitudes have a bigger influence more prosumers' *interest to collaborate* than on the consumers' interest to collaborate, while its performance is higher in respect of prosumers (Fig. 3). Furthermore, since this construct's importance is rather low, and its performance is high, it already leads quite efficiently to

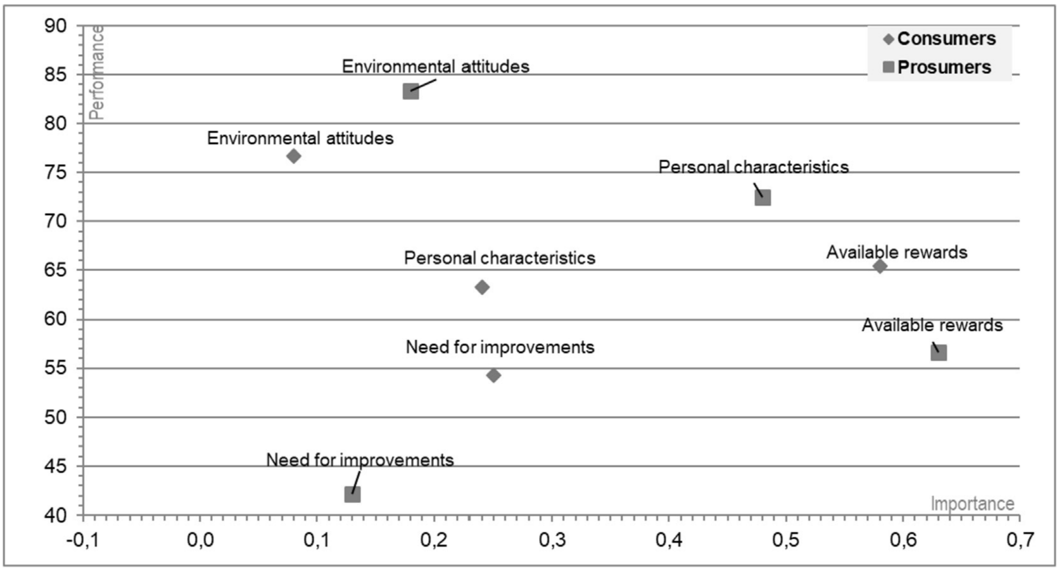

Fig. 3. IPMA results of the second-order constructs.

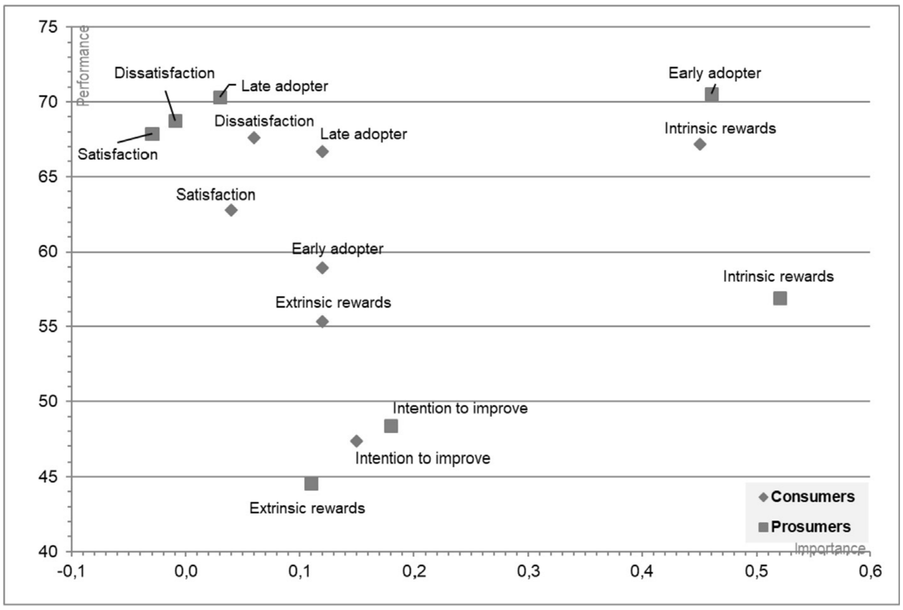

Fig. 4. IPMA results of the first-order constructs.

co-creation. On the other hand, *available rewards* are highly important, but have a rather low performance, and, according to our data, they – rather than prosumers – lead consumers to co-creation. At the same time, well-targeted rewards could increase the probability of prosumers undertaking co-creation activities. In addition, the importance of the *need for improvements* and the *personal characteristics* clearly differs in terms of prosumers and consumers. As a result, we must examine the first-level constructs' IPMA closer.

The IPMA (Fig. 4) shows that *intrinsic rewards* consistently drive both consumers' and prosumers' interest to co-create. Moreover, intrinsic rewards are highly important for prosumers, which could be further enhanced, since their performance is currently low. Furthermore, both intrinsic rewards and extrinsic rewards currently have more influence on consumers' interest to collaborate than that of prosumers, since the former's performance value is higher. A noteworthy result is that *early adopter* characteristics drive prosumers' interest to co-create, while these characteristics have very little importance for consumers.

5. Conclusions

Energy market transition, largely enabled by new affordable energy technologies and digitalization, opens novel opportunities for growth through introducing innovative energy solutions. An understanding of the energy consumers' and prosumers' potential to innovate can give companies an advantage in the changing energy markets. This research focuses on studying the microfoundations of end users' interest to collaborate in RET. We hypothesized and tested the impact of the following aspects on users' interest to collaborate in value co-creation: personal characteristics, need for improvements, available rewards, and environmental attitudes.

In terms of our first research question, “What are the microfoundations of end user interest to collaborate in the co-creation of RET innovations,” our results emphasize the role of personal characteristics and available rewards as the microfoundations for the interest to collaborate. The findings confirm that giving rewards has a positive association with collaboration interests. Furthermore, in accordance with earlier research, intrinsic rewards apparently work best as motivators of co-creation and collaboration. Similarly, early adopter characteristics contributed significantly toward the interest to collaborate. According to our results, the role of needs for improvement and environmental attitudes do not significantly influence interest for co-creation. Furthermore, available rewards could be used much more efficiently to engage prosumers in co-creation activities (see Figs. 3 and 4).

Regarding the second research question, “How energy consumers and prosumers differ in their interest to collaborate,” our research suggest that there are differences between these two adopter groups. The results, for instance, indicate that especially prosumers exhibit early adopter characteristics, thereby making them potentially a highly valuable group for collaboration, because they already have access to RET and may have high quality ideas for new functionalities, process improvements, services, and applications. Finding the right ways of engaging would further involve more rewards based on intrinsic motivations. This information could help industry actors better target their co-creation incentives.

The empirical analysis in this study also has its limitations, because it only included a subset of the aspects that need to be considered when studying the co-creation behavior of consumers and prosumers. Another limitation naturally is the small sample size, which means that we can only cautiously compare the results for consumers and prosumers. The Smart-PLS analytics tool is, nevertheless, well equipped to analyze small sample sizes, due to its ability to apply the bootstrapping method.

Future research could study energy consumers and prosumers as value co-creation participants based on our findings, for example, by considering a wider set of personal characteristics and environmental attitudes. Additional interesting areas for future research include: prosumers and consumers interest in co-creating in technical solutions, business models, services, or concept development. Furthermore, this research area offers worthwhile future research avenues for energy system actors with regards to utilizing users' experiences in the digitalization-, electrification-, and decentralization-driven transformation.

Acknowledgements

M.Sc. students Jussi Valta and Elisa Lukin at Tampere University of Technology supported the research by collecting survey data.

Appendix A. Measurement model constructs.

1st order Construct	*2nd order construct*	*Measurement item*	
Interest to collaborate		1) I would be interested in … giving feedback on renewable energy related products (panels, meters, etc.)	EIRe1
		2) … giving feedback on Renewable Energy related services (support, automatic energy monitoring, etc.)	EIRe2
		3) … validating new business models	EIRe3
		4) … providing ideas for new product functionalities and services	EIRe4
		5) … co-development of products and services (e.g. coding, design) together with Renewable Energy product and service companies	EIRe5
		6) … testing products and services (before they come commercially available)	EIRe6
Early adopter	Personal characterisics	1) I am interested in new technologies	InvDDI1
		2) I consider myself a technology expert	InvDDI2
		3) I like to modify products to enhance their functionalities	InvDDI3
		4) I recommend new products and services to my colleagues, friends and family	InvDDI4
Late adopter		1) I seek frequently help from others for product related performance issues	InvDDI5
		2) It is important to me that the renewable energy system is easy to use	InvDDI6
		3) Recommendations of others are important to me	InvDDI7
		4) Technology is certified by authorities.	InvDDI8
Pro-environmental attitudes		1) It is important for me to increase my green energy usage	InvDGV1
		2) It is important to use Renewable Energy to reduce polluting	InvDGV2
		3) I am interested in paying more for environmentally friendly products and services	InvDGV4
		4) I am knowledgeable about environmental issues	InvDGV5
Dissatisfaction	Need for improvements	1) I give feedback on products … when I am dissatisfied in the product performance	AP1
		2) … when I am dissatisfied with customer support/service	AP2
Intention to improve		1) … to suggest improvement ideas for product functionality	AP3
		2) … to suggest improvement ideas for business model	AP4
Satisfaction		1) … when I am satisfied with product performance	AP5
		2) … when I am satisfied with customer support/services	AP6
Intrinsic	Available rewards	1) Enjoying the process and having fun	Mot10
		2) Learning new things	Mot3
		3) Challenges and competitions	Mot4
		4) Sense of belonging to a community	Mot7
		5) Being part of creating better environmentally sustainable products and services	Mot9
Extrinsic		1) Monetary compensation	Mot1
		2) Gifts & rewards (e.g. gift cards)	Mot2
		3) Career opportunities	Mot5
		4) Exclusive information on Renewable energy systems	Mot6
		5) Recognition of others	Mot8

Appendix B. Demographic information of the survey respondents (N = 197).

Characteristics	Description	%
Age group	18–24	18.4
	24–40	40.3
	40–55	15.3
	>55	26.0
Education	Primary school	4.7
	Secondary school	28.1
	Bachelor's degree	19.3
	Master's degree	47.9
Income	<3000 €	38.5
	3000-6000 €	37.0
	>6000 €	24.5

Declaration of interest

Conflicts of interest: Christian M. Ringle acknowledges a financial interest in SmartPLS. The other authors declare no conflicts of interests.

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References

Adler, J.H., 2011. Eyes on a climate prize: rewarding energy innovation to achieve climate stabilization. Harv. Environ. Law Rev. 35, 1–46.

Agarwal, R., Karahanna, E., 2014. Time flies when you're having fun: cognitive absorption and beliefs about information technology usage. MIS Q. 24, 665–694.

Ajzen, I., 1985. From intentions to actions: a theory of planned behavior. In: Beckman, J., Kuhl, J. (Eds.), Action-Control: from Cognition to Behavior. Springer, Heidelberg, pp. 11–39.

Akehurst, G., Afonso, C., Martins Concalves, H., 2012. Re-examining green purchase behaviour and the green consumer profile: new evidences. Manag. Decis. 50, 972–988.

Albers, S., 2010. PLS and success factor studies in marketing. In: Esposito Vinzi, V., Chin, W.W., Henseler, J., et al. (Eds.), Handbook of Partial Least Squares: Concepts, Methods and Applications, vol II. Springer Handbooks of Computational Statistics Series.

Alves, H., Fernandes, C., Raposo, M., 2016. Value co-creation: concept and contexts of application and study. J. Bus. Res. 69, 1626–1633.

Amabile, T.M., 1996. Creativity in Context: Update to the Social Psychology of Creativity. Westview press.

Antikainen, M.J., Vaataja, H.K., 2010. Rewarding in open innovation communities. How to motivate members ? Technology 11, 440–456.

Aquilani, B., Silvestri, C., Ioppolo, G., Ruggieri, A., 2018. The challenging transition to bio-economies: towards a new framework integrating corporate sustainability and value co-creation. J. Clean. Prod. 172, 4001–4009.

Astarloa, B., Kaakeh, A., Lombardi, M., Scalise, J., 2017. The Future of Electricity: New Technologies Transforming the Grid Edge. World Econ, forum, p. 32.

Ballon, P., Hoed, M. Van, Schuurman, D., 2018. The effectiveness of involving users in digital innovation: measuring the impact of living labs. Telematics Inf. 35 (5), 1201–1214.

Barney, J., Felin, T., 2013. What are microfoundations? Acad. Manag. Perspect. 27, 138–155.

Bigerna, S., Bollino, C.A., Micheli, S., 2016. Socio-economic acceptability for smart grid development—a comprehensive review. J. Clean. Prod. 399–409.

Bryant, S.T., Straker, K., Wrigley, C., 2018. The typologies of power: energy utility business models in an increasingly renewable sector. J. Clean. Prod. 195, 1032–1046.

Butler, M., Nisan, R., 1986. Effects of no feedback, task-related comments, and grades on intrinsic motivation and performance. J. Educ. Psychol. 78, 210–216.

Chen, K.K., 2014. Assessing the effects of customer innovativeness, environmental value and ecological lifestyles on residential solar power systems install intention. Energy Policy 67, 951–961.

Chesbrough, H.W., 2003. Open Innovation: the New Imperative for Creating and Profiting from Technology. Harvard Business School Press., Boston.

Chin, W.W., 2010. How to write up and report PLS analyses. In: Esposito, V.V., Chin, W.W., Henseler, J. (Eds.), Handbook of Partial Least Squares: Concepts, Methods and Applications, vol II. Springer Handbooks of Computational Statistics Series, pp. 655–690.

Clark, C.F., Kotchen, M.J., Moore, M.R., 2003. Internal and external influences on pro-environmental behavior: participation in a green electricity program. J. Environ. Psychol. 23, 237–246.

Cloutier, G., Papin, M., Bizier, C., 2018. Do-it-yourself (DIY) adaptation: civic initiatives as drivers to address climate change at the urban scale. Cities 74, 284–291.

Cooper, R.G., 2014. What's next? After stage-gate. Res. Manag. 57, 20–31.

Davis, F.D., Baggozzi, R.P., Warshaw, P.R., 1992. Extrinsic and intrinsic motivation to use computers in the workplace. J. Appl. Soc. Psychol. 22, 1111–1132.

European commission, 2016. Proposal for a Directive of the European Parliament and of the Council on Common Rules for the Internal Market in Electricity' (Proposal for the Amendment of the Electricity Directive).

Fishbein, M., Ajzen, I., 1975. Belief, Attitude, Intention, and Behaviour: an Introduction to Theory and Research. Addision-Wesley, Reading, MA.

Frederiks, E.R., Stenner, K., Hobman, E.V., 2015. Household energy use: applying behavioural economics to understand consumer decision-making and behaviour. Renew. Sustain. Energy Rev. 41, 1385–1394.

Füller, J., 2010. Refining virtual Co-creation from a consumer perspective. Calif. Manag. Rev. 52, 98–122.

Hair, J.F., Hollingsworth, C., Randolph, A., 2017a. An updated and expanded assessment of PLS-SEM in information systems research. Ind. Manag. Data Syst. 117, 442–458.

Hair, J.F., Ringle, C.M., Sarstedt, M., 2011. PLS-SEM: indeed a silver bullet. J. Market. Pract. J. Mark. Theory Pract. 19, 139–152.

Hair, J.F.J., Hult, G.T.M., Ringle, C.M., Sarstedt, M., 2017b. A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM), second ed. Sage Publications, Los Angeles.

Heiskanen, E., Laakso, S., Matschoss, K., Backhaus, J., Goggins, G., Vadovics, E., 2018. Designing Real-World Laboratories for the Reduction of Residential Energy Use 60–67.

Heiskanen, E., Matschoss, K., 2017. Understanding the uneven diffusion of building-scale renewable energy systems: a review of household, local and country level factors in diverse European countries. Renew. Sustain. Energy Rev. 75, 580–591.

Henseler, J., Ringle, C.M., Sarstedt, M., 2015. A new criterion for assessing discriminant validity in variance-based structural equation modeling. J. Acad. Mark. Sci. Mark. Sci. 43, 115–135.

Hossain, M., 2016. Grassroots innovation: a systematic review of two decades of research. J. Clean. Prod. 137, 973–981.

Hossain, M., 2012. Users' motivation to participate in online crowdsourcing platforms. ICIMTR 2012 - 2012 Int. Conf. Innov. Manag. Technol. Res. 310–315.

Hyysalo, S., Johnson, M., Juntunen, J.K., 2017. The diffusion of consumer innovation in sustainable energy technologies. J. Clean. Prod. J. Clean. Prod. S70–S82.

Hyysalo, S., Juntunen, J.K., Freeman, S., 2013. User innovation in sustainable home energy technologies. Energy Policy 55, 490–500.

IRENA, 2018. Innovation Priorities to Transform the Energy System. International Renewable Energy Agency, Abu Dhabi.

Kaufmann, L., Gaeckler, J., 2015. A structured review of partial least squares in supply chain management research. J. Purch. Supply Manag. 21, 259–272.

Kennedy, E.H., Beckley, T.M., McFarlane, B.L., Nadeau, S., 2009. Why we don't “walk the talk”: understanding the environmental values/behaviour gap in Canada. Hum. Ecol. Rev. 16, 151–160.

Kollmuss, A., Agyeman, J., 2002. Mind the Gap : why do people act environmentally and what are the barriers to pro- environmental behavior? Environ. Educ. Res. 8, 239–260.

Korjonen-Kuusipuro, K., Hujala, M., Pätäri, S., Bergman, J.P., Olkkonen, L., 2017. The emergence and diffusion of grassroots energy innovations: building an interdisciplinary approach. J. Clean. Prod. 1156–1164.

Kotilainen, K., Saari, U.A., 2018. Policy influence on consumers' evolution into prosumers-empirical findings from an exploratory survey in Europe. Sustain. Times 10.

Kotilainen, K., Valta, J., Jarventausta, P., 2018. How consumers prefer to innovate in renewable energy and what they expect to get in return for co-creation. In: 2017 Int. Conf. Eng. Technol. Innov. Eng. Technol. Innov. Manag. Beyond 2020 New Challenges, New Approaches, ICE/ITMC 2017 - Proc, pp. 872–878.

Kruger, C., Caiado, R.G., Franca, S.L.B., Quelhas, O.L.G., 2018. A holistic model integrating value co-creation methodologies towards the sustainable development. J. Clean. Prod. 400–416.

Kumar, V., Aksoy, L., Donkers, B., Venkatesan, R., Wiesel, T., Tillmanns, S., 2010. Undervalued or overvalued customers: capturing total customer engagement value. J. Serv. Res. 13, 297–310.

Lakhani, K.R., Wolf, R.G., 2005. Why hackers do what they Do : understanding motivation and effort in free/open source software projects 1 By. Perspect. Free Open Source Softw 1–27.

Lee, S.M., Olson, D.L., Trimi, S., 2012. Co-innovation: convergenomics, collaboration, and co-creation for organizational values. Manag. Decis. 50, 817–831.

Leminen, S., Rajahonka, M., Westerlund, M., 2017. Towards third-generation living lab networks in cities. Technol. Innov. Manag. Rev. 7, 21–35.

Lowry, P.B., Gaskin, J.E., Twyman, N.W., Hammer, B., Roberts, T.L., 2013. Taking “fun

and games" seriously: proposing the hedonic-motivation system Adoption model (HMSAM). J. Assoc. Inf. Syst. 14, 617–671.
Mamounakis, I., Vergados, D.J., Makris, P., Varvarigos, E., Mavridis, T., 2015. A Virtual MicroGrid platform for the efficient orchestration of multiple energy prosumers. In: ACM International Conference Proceeding Series, pp. 191–196.
Morstyn, T., Farrell, N., Darby, S.J., McCulloch, M.D., 2018. Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants. Nat. Energy 3, 94–101.
Nachira, F., Dini, P., Nicolai, A., 2007. Network of Digital Ecosystems for Europe: Roots, Processes and Perspectives.
Nambisan, S., 2010. Virtual customer environments: IT-enabled customer Co-innovation and value Co-creation. In: Information Technology and Product Development - Annals of Information Systems. Springer, pp. 109–127.
Nesti, G., 2018. Co-production for innovation: the urban living lab experience experience. Polic. Soc. 37, 310–325.
Nielsen, K.R., Reisch, L.A., Thøgersen, J., 2016. Sustainable user innovation from a policy perspective: a systematic literature review. J. Clean. Prod. 133, 65–77.
Nygren, N.A., Kontio, P., Lyytimäki, J., Varho, V., Tapio, P., 2015. Early adopters boosting the diffusion of sustainable small-scale energy solutions. Renew. Sustain. Energy Rev. 46, 79–87.
Ofir, C., Simonson, I., 2001. In search of negative customer feedback: the effect of expecting to evaluate on satisfaction evaluations. J. Mark. Res. 38, 170–182.
Oreg, S., Katz-Gerro, T., 2006. Predicting proenvironmental behavior cross-nationally values, the theory of planned behavior, and value-belief-norm theory. Environ. Behav. 38, 462–483.
Pasetti, M., Rinaldi, S., Manerba, D., 2018. A virtual power plant architecture for the demand-side management of smart prosumers. Appl. Sci. 8.
Peng, D., Lai, F., 2012. Using partial least squares in operations management research: a practical guideline and summary of past research. J. Oper. Manag. 30, 467–480.
Perković, L., Mikulčić, H., Duić, N., 2018. Multi-objective optimization of a simplified factory model acting as a prosumer on the electricity market. J. Clean. Prod. 167, 1438–1449.
Poortinga, W., Steg, L., Vlek, C., 2004. Values, environmental concern, and environmental behavior a study into household energy use. Environ. Behav. 36, 70–93.
Prahalad, C.K., Ramaswamy, V., 2004. Co-creating unique value with customers. Strat. Leader. 32, 4–9.
Reeve, J., Craig, C., 1989. The Interest-Enjoyment Distinction in Intrinsic Motivation. Motiv. Emot [WWW Document].
Ringle, C.M., Sarstedt, M., 2016. Gain more insight from your PLS-SEM results: the importance-performance map analysis. Ind. Manag. Data Syst. 116, 1865–1886.
Ringle, C.M., Wende, S., Becker, J., 2015. SmartPLS 3.
Rogers, E.M., 1995. Diffusion of Innovations, fourth ed. Free Press, Schuster.
Ryan, R., Deci, E., 2000. Self-determination theory and the facilitation of intrinsic motivation. Am. Psychol. 55, 68–78.
Sarstedt, M., Ringle, C.M., Hair, J.F., 2017. Partial least squares structural equation modeling. In: Homburg, C., Klarman, M., Vomberg, A. (Eds.), Handbook of Market Research. Springer, Heidelberg.
Schiederig, T., Tietze, F., Herstatt, C., 2012. Green innovation in technology and innovation management – an exploratory literature review 1. R D Manag. 42 (2), 180–192.
Schot, J., Geels, F.W., 2008. Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. Technol. Anal. Strat. Manag. 20, 537–554.
Shmueli, G., Ray, S., Velasquez Estrada, J.M., 2016. The elephant in the room: evaluating the predictive performance of PLS models. J. Bus. Res. 69, 4552–4564, 69(10).
Shmueli, G., Sarstedt, M., Hair, J.F., Cheah, J., Ting, H., Vaithilingam, S., Ringle, C.M., 2019. Predictive model assessment in PLS-SEM: guidelines for using PLSpredict. Eur. J. Mark. Mark. forthcoming.
Söderlund, M., 1998. Customer satisfaction and its consequences on customer behaviour revisited: the impact of different levels of satisfaction on word-of-mouth, feedback to the supplier and loyalty. Int. J. Serv. Ind. Manag. 9, 169–188.
Steg, L., Dreijerink, L., Abrahamse, W., 2005. Factors influencing the acceptability of energy policies: a test of VBN theory. J. Environ. Psychol. 25, 415–425.
Stern, P.C., 2005. Deliberative methods for understanding environmental systems. Bioscience 55, 976.
Stern, P.C., 2000. Toward a coherent theory of environmentally significant behavior. J. Soc. Issues 56, 407–424.
Szopik-depczy, K., Cheba, K., Iwona, B., Stajniak, M., Simboli, A., Ioppolo, G., 2018. The Study of Relationship in a Hierarchical Structure of EU Sustainable Development Indicators, vol 90, pp. 120–131.
Toft, M.B., Thogersen, J., 2014. Exploring private consumers' willingness to become early adopters of Smart Grid technology. In: 28th International Congress of Applied Psychology.
von Hippel, E., 2005. Democratizing innovation: the evolving phenomenon of user innovation. J. Betriebswirtschaft 55, 63–78.
von Hippel, E., 1986. Lead users: a source of novel product concepts. Manag. Sci. 32, 791–805.
Wolf, M., McQuitty, S., 2011. Understanding the do-it-yourself consumer: DIY motivations and outcomes. AMS Rev. 1, 154–170.

PUBLICATION V

Policy Influence on Consumers' Evolution into Prosumers—Empirical Findings from an Exploratory Survey in Europe

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Policy Influence on Consumers' Evolution into Prosumers—Empirical Findings from an Exploratory Survey in Europe

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Abstract: The energy sector is in transition to a flexible and sustainable energy system based on renewable energy sources. This complex transition is affecting multiple levels in the sociotechnical system. One driver of the transition is climate change that enforces the policy push from the macro level to change the way energy is produced, delivered, and used. As part of the energy system evolution, the role of the end user in the energy sector is undergoing profound changes, and consumers are increasingly being empowered to participate actively in the production and use of energy. This article investigates how policies might affect consumers' interests in becoming prosumers of energy. We explore consumers' attitudes toward using renewable energy technologies (RET) by means of an empirical consumer survey that was conducted in five European countries. The partial least squares structural equation modeling (PLS-SEM) method was utilized to analyze the survey results. Our findings suggest that both economic and non-economic policies affect consumer attitudes toward using renewable energy technologies. We conclude that policies have different effects on consumers and prosumers, who have already made the decision to adopt renewable energy solutions. Based on the findings, we propose a set of policy and managerial implications.

Keywords: energy policy; diffusion; technology acceptance model; prosumer; consumer; renewable energy technology; PLS-SEM

1. Introduction

The main drivers of the transformation in the energy system are the requirement for better energy efficiency due to the ever-increasing demand for energy and the need to increase the use of renewable energy sources because of climate change and the shortage of traditional energy resources [1]. For example, the demand for electricity is expected to increase globally by 80% between 2012 and 2040 [2], which demonstrates the importance of putting energy efficiency on the agendas of governments and policy makers. To meet the growing demand for energy and comply with ecological and economic demands, the structure of the energy market is slowly moving centralized system to a more interactive and decentralized model in which consumers may also play a role as prosumers, that is, as producers and consumers of energy. Furthermore, the roles of the incumbent actors in the energy regime are changing, and new actors are entering the energy market from other industries.

In conjunction with the gradual change in energy production and consumption is the emergence of new technological solutions and business models. Widespread digitalization and industry convergence have created an open network of actors, information, and technology. The integration of the Internet of Things (IoT) into the power grid has led to completely new possibilities for managing the energy system. As a result, the Internet of Energy (IoE) allows real-time data to be collected, transferred, stored, analyzed, and monitored on multiple levels of the energy system, which has opened a range of opportunities to utilize energy production and consumption information.

The transition in the energy industry is complex, and it affects many levels of society. The focus of energy generation is moving from centralized fossil fuel-based power plants toward renewable energy source (RES)-based distributed energy resources (DER). To fulfill its efficiency and sustainability goals, the energy ecosystem will need a dynamic prosumer base to participate in the implementation of the DER as well as to provide flexibility in the grid through demand response (DR). In the energy market, prosumers are seen as niche actors that are potential catalysts of the changing energy system. A frequently used example of an energy prosumer is a household that produces all or part of its energy by using solar panels (solar photovoltaic (PV)) or other renewable energy technology (RET). Although there are many opportunities for consumers to participate actively in the energy markets, many have not yet done so. Moreover, although there is a consensus among policy makers and industry experts that renewable energy solutions should be self-reliant and independent of subsidies in the long run, it is also widely accepted that the diffusion of pro-environmental technologies requires policy support in the early phase of the market. Hence, policy makers around the world are designing policies to remove some of the barriers that are assumed to slow down the consumers' adoption of renewable energy technologies.

The main objective of this research is to evaluate how policies affect consumers' willingness to adopt renewable energy technology-based products and services. Our goal is to evaluate the effects of economic and non-economic policies on consumers' attitudes toward adopting renewable energy technology solutions. The remainder of this paper is structured as follows: Section 2 provides a review of the literature on the theoretical background of the study; Section 3 introduces the conceptual model and the core constructs used in the analysis; Section 4 outlines the data collection and the analysis; Section 5 summarizes the results; Section 6 discusses the findings and their implications for policy and management; and Section 7 concludes the paper.

2. Theoretical Background

2.1. Energy Prosumers, Renewable Energy Technology and the Barriers to Adopting

The concept of a prosumer was first developed by Alvin Toffler, author of *The Third Wave* [3]. Since then, the concept has been defined further by others (e.g., [4]), especially in the context of mass-customization, marketing and media. In the energy field, the definition of a prosumer simply refers to prosumers as consumers who also produce, sell, trade, or store energy [5]. When a more specific definition is required, the use of smart appliances, communication technologies, electric vehicles (EVs) and battery storage capacities for flexible services are included in the definition [6]. In effect, the act of prosuming changes the consumer from merely a reactive end customer to being an active participant in the energy system. At best, prosumers have the potential to create added value not only for themselves but also for the various parties in the energy sector, such as their neighbors, utilities, other energy industry actors, and even society at large.

Some definitions of energy prosumers emphasize different aspects of the prosumer's involvement in the energy field [7]. A technical approach links prosumers to plug-in electric vehicles (EV), energy technologies, automation, and smart buildings. Furthermore, in the social approach to prosuming, the following aspects are often highlighted: prosumers can form energy communities or virtual power plants (VPPs), in which they share or trade energy and thus increase the importance of DER. Prosumers can also be seen as co-creators of innovation through giving feedback, lead-testing products, and participating in co-development [8,9]. Utilities are focusing on extending the DR from industrial customers to households. In this scenario, prosumers could be EV owners with a vehicle-to-grid (V2G) connection [10] that allows them to offer their batteries for balancing loads during peak hours [11].

The concept of RET is broad, and the term is used freely according to the context. Energy prosumers are associated mainly with electricity, but in some cases they are also associated with heating and transport [12]. For example, energy prosumers could use the following technologies: solar photovoltaics (PV), micro wind energy, geothermal energy, small scale combined heat and power (CHP; e.g., biogas), and hydropower. In this research, we refer to RET as a technology, product, or service that enables or supports the use of renewable energy sources (RES) at the household level. The RET technologies that are relevant in our research include: electricity and heating systems based on solar PV, wind turbines and geothermal heat pumps, smart meters, energy monitoring devices and applications, and EVs with battery storage. RET technologies enable consumers to self-produce energy, store energy, sell or share energy as well as monitor and adapt their energy production and consumption. Most RET solutions require the availability of a smart grid technology that enables two-way information and energy flows between production and consumption.

Although there would be multiple rational benefits for consumers to use RET, its diffusion is still in the early market phase. Potential barriers to adopting solar PV are sociotechnical, economic, management related, and policy related [13]. The sociotechnical issues related to adoption are related to concerns about quality and the lack of knowledge of benefits. The perceived complexity of the RET system may have a large impact on adoption [14]. Similarly, concerns about technological maturity, efficiency, and safety can reduce the interest in adopting RET. Risks related to data privacy and security are relevant in smart grids that generate and transfer large amounts of user data. In general, because of the lack of awareness of its benefits, the adoption of RET has been given low priority. Moreover, the optimal RET system requires several components: a smart meter, a solar PV or other energy production system, an energy monitor, an Internet connection, a business agreement with a utility company, and so on. However, to date, turnkey solutions for RET have developed slowly, which adds to the complexity of acquiring RET. Economic barriers to the adoption of RET are often related to the relatively high investment that is required. For example, in some countries, as many as 15–20 years are required to pay back the investment. In addition, the operational costs of RET are not understood or are difficult to calculate by consumers. Because RET systems are generally not profitable without policy support in the early phase, supporting policies are vital tools for the diffusion of RET (e.g., [15]).

2.2. Sustainability Transition of the Energy Markets and the Need for Policy Support

Recent developments in the energy sector, especially in developed countries, indicate that the energy system is evolving into an open, flexible, and sustainable system in which new actors and new business models could flourish. This sociotechnical transition, however, is complex and requires the right windows of opportunity for novel operating modes to emerge and sustain. The multi-level perspective (MLP) [16] suggests that in sustainability, transitions pressure is needed on both the macro-level and the micro-level (i.e., the niche markets), to facilitate changes in the energy regime, which currently aims to remain stable and unchanged. Indeed, energy prosumers can be seen as emerging niche actors whose role is evolving in synchronicity with the rest of the energy industry.

Can and will the prosumer base grow and become a meaningful entity in the future energy system? The role of consumers has been widely acknowledged to be significant in mitigating climate change. Moreover, policy support is a critical accelerator of sustainability transformations. Governments have introduced policy measures to support the adoption of environmentally sustainable solutions that are based on RES and can help in reducing carbon emissions. However, in some cases, the policy incentives are not sufficient. Furthermore, many governments still use subvention to support fossil fuel-based energy use, which can make investments in RES a less attractive option. Policy makers and industry experts agree that macro-level policies in the form of incentives, taxation schemes, and legislative enablers are needed to boost consumers' adoption in the early phases of the diffusion of environmental innovations. Environmental policy instruments (EPI) have been introduced to complement traditional regulations to achieve environmental goals. Basic public policy instruments can be divided into regulatory instruments, financial instruments, and information transfer (e.g., [17]). Their level of coerciveness is often used to categorize the policies (e.g., [18]). Coerciveness is determined by the ways in which the instrument is designed, implemented, and enforced [19]. EPIs can be categorized in several ways. For example, the OECD [20] has used the following categorization: command-and-control, economic instruments, liability and damage compensation, education and information, voluntary approaches, and management and planning. A simpler classification of EPIs refers to them as "market based" and "command-and-control", or "economic" and "non-economic". In this article, we use the latter categorization.

Economic instruments can be effective in promoting desired activities. For example, they have been useful in strengthening market-based drivers to reduce carbon emissions [17]. Economic instruments can be also used to discourage unwanted activities, such as polluting. Examples of economic policies are emission trading schemes, public investments, tax credits, public funding, and subsidies. Economic policy instruments have been found to create lock-ins and path dependencies for technologies. For instance, fossil fuel-based power generation is still widely subsidized because of its importance in economic growth that is often dependent on low-cost energy [21,22].

Non-economic instruments include the command-and-control and soft instruments. Command -and-control instruments are used to support the emergence of the right market conditions for innovative products and services. They include regulations such as carbon emission restrictions, technology and performance standards, feed-in tariffs, and tradable certifications [23]. They also typically impose sanctions in cases where the policies are not followed. Regulation can be efficient in steering toward the desired outcomes, but it has also proven to be resource intensive [24]. Furthermore, although regulations are aimed at all actors, in practice, smaller players with fewer resources and less ability to fight bureaucracy may not be able to benefit from them, which can apply especially to consumers' possibilities to expand their role in the energy sector. Soft instruments include information campaigns, environmental labeling, and voluntary actions. In particular, information tools can be effective in shaping public opinion and in boosting the acceptance of new environmentally friendly solutions [17]. Information tools and building awareness in general play an important role in technology diffusion [25,26].

The policies are also relevant from a sociotechnical viewpoint: most of the command-and-control policies are driven from the macro-level. EU directives, for instance, are meant to influence the system from the top down, whereas innovative voluntary approaches and self-regulation can emerge from the bottom up at the micro-level. Several macro-level policy instruments regulate the possibilities of DR and microgeneration [22,24].

2.3. Diffusion of Innovations

To fully harness the potential of the emerging energy system to be sustainable, there is an urgent need to accelerate the adoption of RES among consumers. The diffusion of innovation (DOI), or innovation diffusion theory (IDT), was first introduced by Rogers [27], who explained the process of innovation adoption over time. A new technology or an innovation is adopted by categories of adopters in a temporal sequence. These adopter categories are as follows: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards [27]. The early market, including innovators and early adopters, adopts the innovation first and the subsequent adopter groups follow. Most innovations fail to cross "the chasm" [28] between the early and the late markets. Special characteristics are related to the diffusion of pro-environmental innovations: consumers may be willing to pay more for environmental innovations; there is a need for policy support in the early phases; and a behavioral change is often required.

According to the IDT, the consumers' acceptance of a new technology takes place in different stages: knowledge, persuasion, decision, implementation, and confirmation. We are especially interested in the persuasion and the decision stages, that is, whether the consumer will adopt or reject RET. The five factors [29] related to the persuasion characteristic in adopting a new technology are relative advantage, compatibility, complexity, trialability, and observability. The factor of relative advantage refers to the net benefits of a new technology or innovation. The perceived costs of adopting an innovative product may decrease the relative advantage. These costs include financial costs and risks, concerns about complexity, and the lack of expected functionality. Concerns about data privacy and energy security may be relevant to energy prosumers and might affect the perceived relative advantage of RET [30]. Benefits related to RET can include savings in energy costs, trophy value, increased awareness of energy consumption, and so on. The economic benefits of RET often materialize over time, which has been found to decrease consumers' interests in adopting PV, for example [31]. The environmental benefits of RET have been studied extensively in the context of technology acceptance and adoption; for example, environmental reasons have been the basis of the main arguments to the usage of smart metering [32,33]. The factor of compatibility refers to how well the new technology fits with the consumer's existing way of living. In cases where the adoption of RET requires changing behavior, the interest may decrease especially if the individual is a late market adopter [29]. A well-known motivation for consumers to change their behavior is a price incentive, which is often induced by policy instruments [34]. Complexity can affect the willingness to adopt; products that are perceived as complex commonly have longer diffusion times than those that appear to be easy to use [29]. Early adopters, who often are technology enthusiasts, are usually not concerned about complexity, whereas mass-market users expect ease of use [29]. The factor of trialability relates to the ability to test the innovation in a risk-free setting at minimal cost. For example, the availability of an option to lease may lower the threshold for adopting a new technology. Trialability is particularly important for early market users who are interested in trying new technologies and giving feedback [29]. Observability is an important factor for late market adopters, who often rely on the recommendations of the peers in their social circles [29].

2.4. Technology Adoption Models

Energy prosumers often need to make considerable financial investments in RET. These initial investment costs and the expected long period before return on investment is realized in the current energy sector undeniably influences consumers' decision-making, such as in relation to solar PV equipment. However, some RET products do not have a significant cost attached. Several other aspects in addition to financial considerations affect consumers' willingness to become active in adopting new energy solutions. The research on active consumers and consumer decision-making is thus multi-disciplinary, and research approaches encompass as least rational economic models (i.e., the consumer or prosumer as a "*Homo economicus*"), behavioral economics, sociology, psychology, and technology adoption and diffusion models. The IDT is one approach to understanding consumers' adoption of energy technologies. Traditional economics considers that consumers rationally optimize their benefits with the resources available. However, the rational approach has been proven to be a great oversimplification of a complex topic [35]. Environmentally sustainable behavior may require additional efforts (e.g., recycling and using public transportation) and behavioral adaptation (energy conservation, energy production, and using EVs). Thus, the complexity of behavioral change related to the consumer decision-making process is widely acknowledged in the literature. The motivation to invest in the self-production of energy is a popular research theme. For example, Balcombe et al. [36] conducted a study on microgeneration adoption and categorized the motivation factors as finance, the environment, security of supply, uncertainty and trust, inconvenience, and impact on residence. Intrinsic and extrinsic motivations [37] have been linked to the adoption of new technologies. The psychological research on consumers' decision-making related to energy and environmental innovations has focused on the value-belief-norm (VBN) theory [38]. Fishbein and Ajzen's theory of reasoned action (TRA) [39] and Ajzen's theory of planned behavior (TPB) [40] have been used in the sociological approach. The TRA and TPB models are central in understanding pro-environmental behavior. Both theories link beliefs, attitudes, perceptions, and subjective norms to intentions that predict actual behavior. The technology acceptance model (TAM) [14,41] and its extensions are based on the same logic; the perceived usefulness and perceived ease of use lead to an attitude toward using something that can predict intentions to use a new technology and an entirely new system.

The original TAM, which was developed by Davis [14], is depicted in Figure 1. The model has six key elements: external factors, perceived ease of use, perceived usefulness, attitude toward using, behavioral intention to use and actual use of the system. Perceived ease of use affects both the perceived usefulness and the attitude toward use. Perceived usefulness also affects the behavioral intention to use, which ultimately influences the actual use of the system. The TAM model shares several similarities with the IDT, and it has been used widely in modeling technology acceptance in various types of information systems (IS) (e.g., [42–45]) and in other fields, such as health technologies [46]. Recently, the TAM and its modifications have been increasingly used in energy and sustainability related studies (e.g., [31,47–49]). The TAM was further developed by Venkatesh et al. [50] into a broader model, which includes social influence and other factors that were not included in the original TAM. Although widely used in research, the technology adoption models have also been criticized as there is evidence that the consumers' pro-environmental attitudes may not be a strong determinant of their actual intentions; several studies have identified gaps between attitudes, intentions and behavior [51–54].

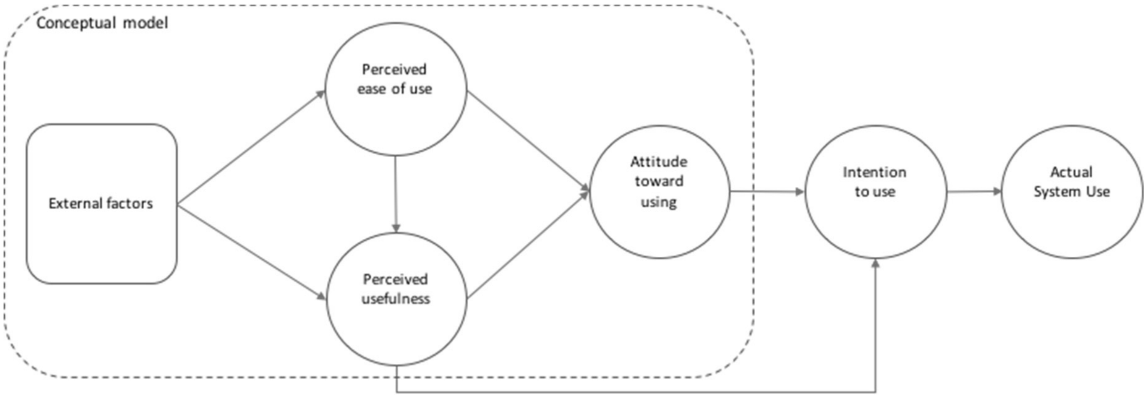

Figure 1. Conceptual model of this research adapted from Davis's [12] technology acceptance model (TAM).

3. Conceptual Model

Our research aims to understand how policy influences the evolution of consumers into prosumers. We approach this aim by seeking to answer the following research questions (RQ):

RQ1: Does policy influence consumer attitudes toward using renewable energy technologies?
RQ2: How do economic or non-economic policies affect consumers' attitude to adopt?

We use the TAM and the IDT and to some extent the TRA as the theoretical basis of this research. These theories have been rigorously tested and proven to work in the context of high technology, in which RET fits perfectly even through to our knowledge, the TAM has not been used to model the influence of policy on technology acceptance. An increasing number of studies have suggested that the TAM, the TRA, or their adaptations can be a suitable tools for modeling RET [55,56]. In addition to TAM, we also utilize the theoretical premises related to environmental policy instrument design in our research design.

To answer the research questions, we constructed a conceptual model as the basis of the empirical research. The model was built in three phases. First, a set of significant barriers to adopting RET were used to connect policies and policy instruments with technology adoption models in order to establish a logical association between the two (see Table 1). The barriers can be linked with the perceived usefulness and the perceived ease of use (in the TAM). To ensure that elements not fully present in the TAM are all taken into consideration, we further linked the barriers to the IDT elements. For example, the lengthy investment payback time is related to the perceived usefulness (in the TAM) as it weighs the value of RET as perceived by the potential adopter [14]. Similarly, the payback time is related to the relative advantage as it measures the overall all cost-benefit ratio of

RET [29,57]. We categorized the policies as either economic or non-economic. For example, economic policies normally include policy instruments such as subsidies, governmental loans and grants, and tax exemptions and non-economic policies include regulation, changes in legislation and bureaucracy, information and education [17,19,23]. These can be associated with the perceived usefulness (in the TAM model) and the relative advantage (in the IDT) of the technology. In the case of the lengthy investment payback time, using economic policies have been found to be effective [17]. The rest of the adoption barriers were linked to theory (TAM and IDT) and further to the policy types and policy instruments in the corresponding manner.

Table 1. Policy intervention instruments for removing the barriers to adopting RET and their relationship with technology adoption theories (TAM and IDT).

Barrier to Adopting RET	TAM [14]	IDT [29]	Policy Type	Policy Instrument
Lengthy investment payback time (e.g., [57,58])	Perceived usefulness	Relative advantage	Economic	Subsidies, grants, low interest loans, tax exemptions
Operational costs are unknown (e.g., [59])	Perceived usefulness	Relative advantage	Economic	Tax exemptions, feed-in-tariffs, incentive schemes
	Perceived usefulness	Relative advantage	Non-economic	Information campaigns
Ease of use is of concern (e.g., [60])	Perceived ease of use	Complexity	Non-economic	Information campaigns, straightforward permissions
RET benefits are not understood (e.g., [61,62])	Perceived usefulness	Relative advantage	Non-economic	Information campaigns
No interest (e.g., [61])	Perceived usefulness	Compatibility	Non-economic	Information campaigns
Security and privacy concerns (e.g., [30,63])	Perceived usefulness	Relative advantage	Non-economic/ economic	Information campaigns, data privacy laws, secure mgmt. of cost related data
Availability of turnkey solutions (e.g., [64])	Perceived ease of use	Complexity	Non-economic	Commercialization support, Information campaigns
Regulatory barriers exist (e.g., [65,66])	Perceive usefulness	Complexity	Non-economic	Changes in legislation, regulation, bureaucracy

Second, we defined the measurement items and the core constructs that are used in the empirical research. The economic policy instruments include financial incentives such as subsidies, loans and grants, tax reliefs and penalties, tariffs, ways of reducing monthly electricity bills. and ensuring the safety of consumption data [17,19,23]. Correspondingly, the non-economic policy instruments encompass both command-and-control instruments and soft instruments. They include information campaigns, regulations, laws, permits, and standardizing [17,19,23]. The constructs for economic policy (EP) and non-economic policy (NEP) were created based on adaptation from these commonly used environmental policy instruments; for example, a subsidy or grant is an economic policy instrument. Subsequently, the measurement items related to the policy instruments were designed for the EP and NEP constructs adapting them from earlier research (as indicated in the Table 2). For example, the importance of subsidy or grant when considering RET investment was adapted from Faiers [57] and was operationalized as measurement item for EP1: "I can get a grant from the government for the investment". Similarly, policies related to the security and accuracy of data were operationalized as: "My consumption data is being managed securely by my energy utility" (EP5, see e.g., [67]). Table 2 summaries the policy related constructs EP and NEP.

Third, after defining the policy-related core constructs and the survey items, we then used the original version of the TAM [14] as the foundation for the rest of the conceptual model. First, we created constructs for perceived ease of use and perceived usefulness first. Because the TAM has only one element for "perceived usefulness" (PU), we wanted to understand how economic policy and non-economic policy affect perceived usefulness and whether it was then necessary to divide PU into two parts: economic and non-economic. In earlier research, PU was not split; therefore, our approach is explorative because it deviates from the TAM in this regard. Constructs presented in

Table 3 were created to test perceived economic (PUE) and perceived functional usefulness, which we termed as perceived usefulness, functional (PUF). For example, possibility to generate revenue using RET can affect how relative advantage (as in the IDT) or PU (as in the TAM) are perceived. This can be operationalized as in PUE1: "I can sell excess energy to utility company". The rest of the PUE and PUF constructs were created in the similar manner, adapting or modifying them from earlier research (see Table 3). The Table 3 also introduces the constructs related to perceived ease of use (PEOU). For example, complexity (as in the IDT) and perceived ease of use (as in the TAM) can affect the willingness to adopt [14,29]: In case there are signs that the new technology is considered too complex, the threshold for adoption can be lowered by reducing complexity or enhancing the perceived ease of use by for example introducing ready to use solutions (e.g., [64]). This was operationalized using measurement item for PEOU1: "Ready to use solution (equipment, installation, maintenance, business model) is available". The rest of the PEOU constructs were created analogously based on earlier research (see Table 3).

Table 2. Economic policy (EP) instruments and non-economic policy (NEP) instruments.

Policy Instrument	Measurement Item	Construct
Subsidy or grant	I can get a grant from the government for the investment.	EP1 [57]
Tax benefit	I will have tax benefits the investment.	EP2 [68]
Tax penalty	I will not get tax penalties for my energy production.	EP3 [69]
Tariff structure	I can reduce my monthly electricity bill.	EP4 [57]
Security and accuracy of consumption data	My consumption data is being managed securely by my energy utility.	EP5 [67]
Regulation, legislation	The bureaucratic process is easy when connecting. Renewable Energy system to the grid.	NEP1 [36]
Information campaigns	I have a clear understanding on how the tariffs and other subsidies work.	NEP2 [68]
	Renewable Energy system provides real time information of my energy production and use.	NEP3 [70]

Constructs were adapted from the sources indicated in the table.

Table 3. TAM- and IDT-related constructs: perceived usefulness, economic (PUE), perceived usefulness, functional (PUF), and perceived ease of use (PEOU).

TAM, IDT with RET Examples	Measurement Item	Construct
Relative advantage/PU: Potential revenue	I can sell my excess energy to utility company.	PUE1 [71]
Relative advantage/PU: predictable revenue streams	I will get a guaranteed fixed price for the excess energy I sell (e.g., fixed feed-in tariffs).	PUE2 [36]
Relative advantage/PU: Availability of useful information	I can get information of electricity price peaks.	PUF1 [70]
Relative advantage/PU: Availability of useful services	Availability of services that allow easy access to monitor both production and use of the system.	PUF2 [69]
Compatibility/PU: ability to manage the system	I can adjust the energy system configurations myself.	PUF3 [70]
Relative advantage/PU: free from utility	Energy autonomy (energy production independently from utility).	PUF4 [72]
Complexity/PEOU: low threshold to purchase	Ready- to use solution (equipment, installation, maintenance, business model) is available.	PEOU1 [64]
Complexity/PEOU: technical installation	The easiness of installation.	PEOU2 [36]
Complexity/PEOU: Availability of turnkey solution	All the equipment and installation are available from a single, one-stop shop.	PEOU3 [64]

Constructs were adapted from the sources indicated in the table.

Attitudes toward adopting technology have been studied widely from the behavioral, environmental, social, and psychological perspectives. Subjective norm is used in both TRA [39] and TPB [40] as it has been found to affect attitudes and intentions toward adopting environmental innovations through feeling obligated to adjust one's behavior to act in a more sustainable manner. In our research, the corresponding construct ATU1 is operationalized as: "It is important for me to increase my green energy usage". According to the TPB, normative beliefs have influence on subjective norm as they reflect one's beliefs of how other's think she or he should or should not act [40]. To reflect this notion, ATU2 was adapted from earlier research [69]. Attitude toward a specific behavior (as in the TRA) is also relevant in the case of RET and examples from earlier research are available (e.g., [70,73]). We hence used measurement items related to attitudes toward willingness to paying more (ATU3) and toward washing dishes and laundry during non-peak hours (ATU4). The ATU constructs are summarized in the Table 4.

Table 4. Constructs related to attitude toward using (ATU).

TRA, TPB	Measurement Item	Construct
TPB/TRA: Subjective norm	It is important for me to increase my green energy usage.	ATU1
TPB: Normative belief	It is important to use Renewable Energy to reduce polluting.	ATU2
TRA: Attitude to the specific behavior	I am interested in paying more for environmentally friendly products and services.	ATU3
TRA: Attitude to the specific behavior	I would be interested in e.g., washing dishes and laundry during non-peak hours to save energy.	ATU4

Finally, all the constructs used in this research were defined, and the conceptual model was created. To build the conceptual model, we used three logical steps to link policies and attitudes toward adopting RET: intervention, induction, and immersion. We hypothesize that policy interventions are likely to affect how ease of use and usefulness are perceived, which then affect attitudes toward adopting RET. The TAM was used as the basic framework of the conceptual model, and it was adapted to fit the scope of this research.

The EP and NEP interventions were positioned as factors external to the TAM model. External factors are the antecedents of PEOU and PU, such as individual differences, system characteristics, social influence, and facilitating conditions [74,75]. To our knowledge, policy intervention has not been studied as a factor external to the TAM. In our model, both EP and NEP connect to PEOU, PUF and PUE, which then are linked to ATU. Additionally, as in the original TAM model, PEOU is linked to PUF. Conversely, PEOU is not linked to PUE; there is no earlier evidence or reason to assume that ease of use would enhance how economic benefits are perceived. Because dividing PU into two separate constructs is an explorative approach with the TAM, we considered excluding the relationship between PEOU and PUF. However, because the TAM normally exhibits a strong connection between PEOU and PU [76], it was included in the model. However, our model excludes TAM's elements of "intention to use" and "actual use" of the system. Even though energy policy has not been extensively examined in relation to the TAM, previous research using the model found that various external factors influenced PEOU and PU and thus could affect attitudes toward using a technology solution [14,76,77]. Hence, our model uses policy as an external factor, and we explore the effects of economic policies and non-economic policies on consumers' attitude to using RET. The conceptual model is depicted in Figure 2.

After designing the conceptual model, we developed several hypotheses based on the research questions. We focused on consumers that did not yet have access to RET system, that is, "non-adopters" and "non-prosumers". We included in the study a control group of prosumers who already were users of RET, that is, "adopters". Because we are interested in how policy affects consumers' willingness to evolve into prosumers, our main focus is on consumers' attitudes toward the adoption of RET.

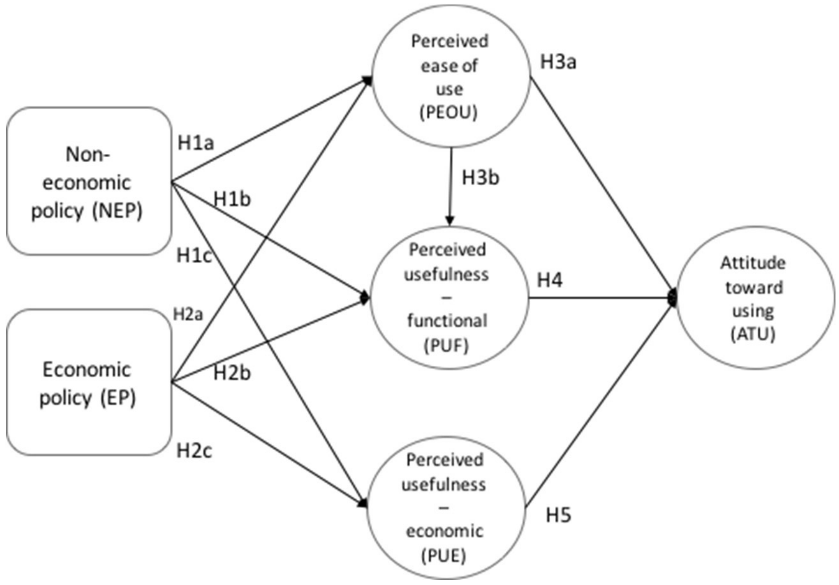

Figure 2. Conceptual model and hypotheses.

To analyze in influence of both economic and non-economic policies, perceived usefulness (in the TAM) was divided into two parts: economic usefulness (PUE) and non-economic (functional) usefulness (PUF). In addition, we connected NEP and EP to PEOU, as at this stage we wanted to determine whether both EP and NEP affected perceptions of ease of use. We hypothesized that both NEP and EP influence consumers' perceptions of the usefulness of RET. Thus, NEP and EP were connected to PUF and PUE. Consequently, the following hypotheses are stated:

Hypothesis 1a. *H1a: Non-economic policy (NEP) instruments influence how non-adopters perceive the ease of use of RET.*

Hypothesis 1b. *H1b: NEP instruments influence how non-adopters perceive the functional usefulness of RET.*

Hypothesis 1c. *H1c: NEP instruments influence how non-adopters perceive the economic usefulness of RET.*

Hypothesis 2a. *H2a: Economic policy (EP) instruments influence how non-adopters perceive the ease of use of RET.*

Hypothesis 2b. *H2b: EP instruments influence how non-adopters perceive the functional usefulness of RET.*

Hypothesis 2c. *H2c: EP instruments influence how non-adopters perceive the economic usefulness of RET.*

Previous research found that perceived ease of use could affect consumers' attitudes toward using a system through increasing the perceived usefulness [32,78]. There is little evidence that economic factors affect perceptions of the ease of use. Hence, the influence of PEOU is tested only against perceived functional usefulness. Because PU is divided into two parts in our research, the connection between PEOU and PUF is inferred. We also assume that PEOU affects the AU of RET as in the original TAM. Therefore, the following hypotheses are stated:

Hypothesis 3a. *H3a: Perceived ease of use (PEOU) influences non-adopters' attitude toward using RET.*

Hypothesis 3b. *H3b: PEOU influences how non-adopters perceive the functional usefulness of RET.*

In the TAM, perceived usefulness usually has a strong connection to attitude toward using a technology [76]. Because we use the novel approach of dividing PU into two parts, it can only be presumed that both PUF and PUE influence AU. Hence, the following hypotheses are stated:

Hypothesis 4. *H4: Perceived functional usefulness (PUF) influences non-adopters' attitude toward using RET.*

Hypothesis 5. *H5: Perceived economic usefulness (PEU) influences non-adopters' attitude toward using RET.*

All hypotheses were tested empirically using a consumer survey as the research method.

4. Research Methodology and Data

The data were collected in a survey conducted in Europe (i.e., France, Germany, Switzerland, Belgium, Italy, and Finland) (N = 197). The respondents included both consumers (N = 122) and prosumers (N = 75). The survey was conducted in July 2016 and January 2017. To ensure content validity, the items chosen for the constructs were adapted from previous research as far as it was possible and the rest of the constructs were designed by the authors to fit the research scope. The constructs were tested with native speakers from all countries (N = 8) and minor changes to the wordings were made accordingly to ensure validity of the questionnaire.

A printed questionnaire was distributed by hand by research assistants and in an online web survey. The questionnaire was completed by the majority of the respondents while the interviewer was present so that the respondents could check the meanings of questions if they did not fully understand them. The respondents could choose to complete the questionnaire online, and some respondents used this option.

The aim of the data collection was to obtain a data set that included approximately the same number of consumers and prosumers in each country. Because of the exploratory approach used in this study, the size of the full data set (N = 197) was sufficient for analyzing the differences between the consumers and prosumers. The questions included in the survey were translated from English by native speakers to the languages of the respondents (i.e., French, German, Italian, and Finnish). The translators also piloted the questionnaire and provided feedback on it. The questions in the survey were formulated as statements so that they could be answered using a 7-point Likert scale from 1 = strongly disagree to 7 = strongly agree.

The respondents first were approached in public spaces, such as parks, airports, and railway stations. However, because very few prosumers were found in these spaces, the research assistants subsequently approached houses that had solar panels on the roof. Satellite images in Google Maps were used to find these houses. In both approaches to the data collection, the response rate was approximately 30%. The use of Google Maps to select houses with solar panels may have resulted in some bias in the sample because the income levels or political views of the inhabitants may be similar in specific living areas. In addition, it should be noted that the demographics were slightly biased by this approach: in Germany and Switzerland, the number of young adults (25–40 years) was higher than the number of middle-aged adults (41–55 years). However, in France and Italy, the overall age distribution was representative of the overall population even though the number of older adults (55 and older) was slightly higher. The demographic profiles of all respondents in the sample is presented in Table 5.

We explored the model fit of the novel conceptual model by first conducting an analysis of variance (ANOVA) and a principal component analysis (PCA) in SPSS. We then utilized partial least squares structural equation modeling (PLS-SEM) according to the guidelines in Hair et al. [78]. PLS-SEM allows the exploration of theories and novel conceptual models using small sample sizes when the theory has not yet been fully developed and the model is complex [79,80]. We used the IBM SPSS version 24 for the PCA analysis and SmartPLS tool (version 3.2.6.) for the PLS-SEM. In the analysis, missing data were handled using the missing-at-random (MAR) approach [80], so the responses were calculated and reweighted with unbiased estimates in cases where the response rates differed [81].

Table 5. Demographic profile of the respondents (N = 197) representing the households.

Characteristic	Description	Share of Respondents (%)
Age group	18–24	18.4
	25–40	40.3
	40–55	15.3
	>55	26.0
Educational level	Primary school	4.7
	Secondary school	28.1
	Bachelor's degree	19.3
	Master's degree	47.9
Household income/month	<3000 €	38.5
	3000–6000 €	37.0
	>6000 €	24.5

5. Results

First, we conducted the ANOVA, which indicated items that differentiated the ways that the consumers and prosumers perceived, assessed, and accepted renewable energy technologies. Then, we conducted the PCA with all of the items in the model construct to determine how the items loaded on various factors. PLS-SEM was used to analyze how EP and NEP influenced the PEOU, PUF, and PUE constructs that might influence the respondents' ATU.

The ANOVA was conducted using the items that measured differences in the attitudes and perceptions of the prosumers and consumers. The comparison of the results showed that the items that differed significantly between the two respondent groups, were in the constructs reflecting economic aspects of policy support (EP), perceived ease of use (PEOU), perceived usefulness, functional (PUF), perceived usefulness, economic (PUE), as well as the actual attitude toward use (ATU) (see Table 6).

Table 6. Analysis of variance between the attitudes of the prosumers and the consumers.

Measurement Item	Construct	Sig.
My consumption data being managed securely by my energy utility	(EP 4)	0.096 *
All the equipment and installation are available from a single, one-stop shop.	(PEOU 3)	0.047 **
Ready to use solution (equipment, installation, maintenance, business model) is available.	(PEOU 1)	0.080 *
I can get information of electricity price peaks.	(PUF 1)	0.058 *
It is important for me to increase my green energy usage.	(ATU 1)	0.048 **
I can sell my excess energy to utility company.	(PUE 1)	0.046 **

Note: ** $p < 0.05$, * $p < 0.10$.

Because there were clear differences in the means of several items used to measure the consumers and the prosumers, and they were statistically significant, we also carried out permutation tests to compare the statistical differences in the path coefficients between the two respondent groups. The results of the permutation test indicated that the total effects of NEP on ATU ($p < 0.05$) and PUE on ATU ($p < 0.10$) differed significantly between the consumers and the prosumers (Table 7).

The results of the permutation test support the approach used to analyze the two groups of respondents separately to verify the influence of policy support on consumers' attitudes toward RET. The detailed findings regarding the individual hypotheses are discussed in Section 5.

Next, we continued to assess the conceptual model with PCA. The Kaiser–Meyer–Olkin (KMO) measure for sampling adequacy was 0.781 in the sample, which allowed us to proceed with the factor analysis using PCA [82]. The first PCA indicated that the items loaded on seven different components. However, in the analysis for construct validity, one component did not fit the model, as the Cronbach's alpha for it was clearly below 0.7 which is the recommended threshold [82]. We then dropped this item (ATU4), and proceeded with another PCA on the model. The KMO for the reduced set of measures was 0.777, which permitted to proceed with PCA [82]. The second PCA resulted in six components, which are shown in Table 8.

Table 7. Permutation test results for the total effects on prosumers and consumers.

	Prosumers	Consumer	Permutation *p*-Values
PEOU → ATU	0.070	0.323	0.118
PEOU → PUF	0.309	0.096	0.330
EP → ATU	0.116	0.136	0.893
EP → PEOU	0.218	0.172	0.743
EP → PUE	0.339	0.509	0.284
EP → PUF	0.398	0.409	0.909
NEP → ATU	0.062	0.243	0.014
NEP → PEOU	0.175	0.520	0.058
NEP → PUE	0.193	0.237	0.877
NEP → PUF	0.138	0.368	0.162
PUE → ATU	0.221	−0.056	0.074
PUF → ATU	0.080	0.278	0.274

Table 8. The six components included in the conceptual model.

Measurement Item	EP	ATU	PEOU	NEP	PUE	PUF
EP 1	0.807	0.133	0.106		0.168	
EP 2	0.774	0.103			0.332	
EP 3	0.619	0.180	0.132	0.324	−0.258	
EP 4	0.510			0.162	0.252	0.180
EP 5	0.481	0.181	0.132		0.334	0.189
ATU 1	0.187	0.826		0.234		
ATU 2		0.783				
ATU 3	0.169	0.778	0.257	0.189	0.118	
PEOU 1			0.849	0.123		0.110
PEOU 2	0.177		0.772	0.139		0.105
PEOU 3	0.156	0.147	0.680	0.138	0.227	0.106
NEP 1		0.103		0.864	0.182	
NEP 2	0.162	0.274	0.217	0.658	0.168	
NEP 3	0.344	0.107	0.260	0.617		0.138
PUE 1	0.215		0.169	0.139	0.812	0.121
PUE 2	0.311			0.180	0.811	
PUF 1	0.230	−0.156		−0.103		0.727
PUF 2		0.178	0.244			0.645
PUF 3	0.308	−0.202	0.104		0.209	0.591
PUF 4	−0.123	0.155	0.154	0.230	0.159	0.567

Rotation method: Varimax with Kaiser normalization.

Based on the six components, the conceptual model showed how the influence of EP and NEP affected PEOU, PUF, and PUE and how they all influenced the ATU. PLS-SEM was used to analyze the influence of the constructs in the model on the attitudes of the respondents. The constructs and their match with the properties of the other constructs in the conceptual model were verified by applying Cronbach's alpha, composite reliability (CR), average variance extracted (AVE), and the factor loadings. The model was analyzed in two phases: First, we analyzed the construct reliability and validity of the measures [78]. Second, we checked the structural model by assessing the factor loadings. The inner weighting scheme used for the PLS-SEM was the path mode.

CR was utilized to evaluate the reliability of the constructs [83]. The CR and the validity of the model for the data on the consumers (N = 122) was excellent in all constructs. For the full data set (N = 197), the construct validity was also acceptable, with the exception of one construct where Cronbach's alpha and AVE were slightly below the recommended values.

We continued to analyze the model using the consumer data because the CR was higher than for the prosumer data. All the CR values were well above the recommended threshold of 0.7 [84], which is an indication of convergent validity. The AVE for all components was higher than the recommended threshold of 0.5. The factor loadings for most of the components were higher than 0.7, which indicated that the variance in the variables could be described by the construct [78]. In only two items, the factor loadings were slightly below 0.6, which was acceptable according to the SEM literature [82] (see Table 9).

The structural model with the non-prosumer data was further assessed by standard model estimation, bootstrapping, and blindfolding procedures in SmartPLS. To check the collinearity of the structural model, the quality criteria, or collinearity statistics (VIF) values were verified. All the inner VIF values were below the required threshold of 5, which indicated that in the predicting constructs, collinearity was not critical [78].

Then, we ran in SmartPLS 500 subsample estimates for all of the variables in order to verify the accuracy of the PLS estimates. The R^2 measure helps to assess the predictive accuracy of a model [78]. R^2 values can range between zero and 1; when the value is close to 1, the predictive accuracy is high. However, in the consumer behavior literature, when the R^2 values are 0.20 or above, they are considered high. For this reason, the R^2 values should not be the only criterion for accepting a model [78]. For the ATU construct, in the case of the non-prosumer data, the R^2 value was 0.213. The R^2 values in the remaining constructs were as follows: PEOU (0.399), PUE (0.449), and PUF (0.475).

Table 9. Analysis of the model with consumer data: descriptive statistics and construct properties.

Construct	Item	MV	SD	Standard Loading	CA	CR	AVE
Policy (non-economic)	NEP 1	6.09	1.311	0.822	0.738	0.851	0.656
	NEP 2	5.60	1.579	0.824			
	NEP 3	5.56	1.477	0.784			
Policy (economic)	EP 1	5.20	1.799	0.829	0.801	0.862	0.560
	EP 2	5.55	1.765	0.834			
	EP 3	6.10	1.523	0.671			
	EP 4	5.20	1.793	0.598			
	EP 5	6.13	1.263	0.780			
Perceived ease of use	PEOU 1	5.73	1.314	0.867	0.824	0.895	0.739
	PEOU 2	5.78	1.289	0.876			
	PEOU 3	5.43	1.580	0.837			
Perceived usefulness, functional	PUF 1	5.20	1.569	0.791	0.704	0.817	0.533
	PUF 2	5.64	1.290	0.559			
	PUF 3	5.52	1.614	0.679			
	PUF 4	5.53	1.598	0.856			
Perceived usefulness, economic	PUE 1	5.66	1.464	0.934	0.862	0.935	0.879
	PUE 2	5.46	1.612	0.941			
Attitude toward use	ATU 1	5.70	1.443	0.906	0.815	0.888	0.727
	ATU 2	6.23	1.286	0.917			
	ATU 3	5.12	1.441	0.721			

Mean value (MV); Std. dev. (SD); Cronbach's alpha (CA); Composite reliability (CR); Avg. variance extracted (AVE).

In addition to the R^2 values, the change in the R^2 values when a specified construct was eliminated from the model was assessed by the f^2 effect size. The thresholds of f^2 are the following: 0.02 = small effect size; 0.15 = medium effect size; and 0.35 = large effect size. Effect sizes below 0.02 indicate no effect [78]. Only the effect sizes of the PEU-construct on PUF and the PUE-construct on AU showed no effect; otherwise, the effect sizes were greater than the small and medium thresholds. The following constructs had large effect sizes: the effect of EP on PUE (0.36) and the effect of NEP on PEOU (0.35).

Q^2 indicates the predictive relevance of the endogenous constructs (i.e., PEOU, PUF, PUE, and ATU). In SmartPLS, the predictive relevance was analyzed using the blindfolding procedure. The results of the construct of cross-validated redundancy showed the final Q^2 values: ATU (0.129), PEOU (0.259), PUE (0.360), and PUF (0.211). Because all Q^2 values were above 0, the model had predictive relevance in the case of these constructs.

The Fornell–Larcker criterion is used to assess discriminant validity. However, the heterotrait–monotrait ratio (HTMT) is also used for this purpose, and it is regarded as a more reliable criterion [78]. The HTMT of the correlations was used to assess the discriminant validity of the components [78]. The HTMT distribution was shown in the results of bootstrapping in SmartPLS. If the HTMT ratio of the path models of the construct is below 0.85, the concepts are distinct [85]. For the constructs in our model, all HTMT values were below 0.85 (see Table 10).

Table 10. Fornell–Larcker criterion and the HTMT values of the consumer data.

	ATU	PEOU	EP	NEP	PUE	PUF
ATU	0.853					
PEOU	0.403 (0.468)	0.860				
EP	0.373 (0.447)	0.461 (0.560)	0.748			
NEP	0.415 (0.521)	0.616 (0.782)	0.556 (0.740)	0.810		
PUE	0.230 (0.258)	0.426 (0.503)	0.640 (0.733)	0.520 (0.654)	0.937	
PUF	0.385 (0.463)	0.473 (0.614)	0.613 (0.771)	0.595 (0.815)	0.577 (0.724)	0.730

Note: The HTMT values of the correlations are in parentheses.

The evaluation of the total effects showed how the formative constructs EP and NEP influenced the target variable ATU through the mediating constructs PEOU, PUF, and PUE (see Table 11). The analysis of the total effects of the exogenous constructs (EP and NEP) on the ATU construct showed that NEP (0.243) had a stronger total effect on ATU than EP did (0.136).

Table 11. All effects of the constructs on the target variable.

	ATU	PEOU	EP	NEP	PUE	PUF
ATU						
PEOU	0.323					0.096
EP	0.136	0.172			0.509	0.409
NEP	0.243	0.520			0.237	0.368
PUE	−0.056					
PUF	0.278					

The path coefficients of the model were estimated using the bootstrapping method in SmartPLS. We used a significance level of 0.05 for the path coefficients because this study is exploratory [78]. The value and significance of the path coefficients for the constructs in the case of the data collected from non-prosumers are shown in Figure 3.

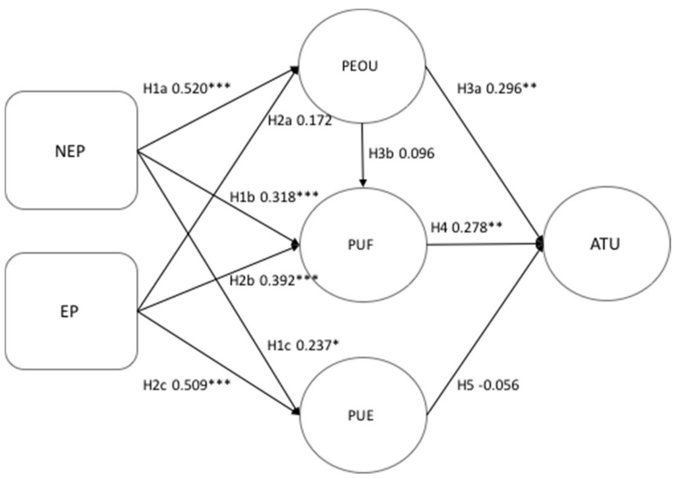

Figure 3. PLS-SEM results for the data on non-prosumers (N = 122). The figure shows the path coefficients. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

6. Discussion

The findings of our research show that there are clear differences in how economic and non-economic policies influence the attitudes of consumers and prosumers. Seven of the ten hypotheses related to consumers (non-adopters) were supported as shown in Table 12.

Hypotheses 1a, 1b, and 1c were supported because the model exhibited a positive relationship with NEP instruments and PEOU, PUF and PUE. The support for PUE (H1c) was weaker than for PUF (H1b), which is logical. However, the results suggest that non-economic policy instruments would add to the perceived economic usefulness of RET. Hypotheses 2b and 2c were also supported by the model, suggesting that economic policy instruments also could be associated with perceived usefulness, whether functional or economic. However, Hypothesis 2a was rejected (95% significance level), indicating that economic policies do not affect how the ease of use is perceived. This finding was interesting because the original PU was divided into two parts. The rejection of the hypothesis indicates that PU could be split without disturbing the TAM's consistency because the rejection seems commonsensically sound.

Hypothesis 3a was supported, which implies that, as shown in earlier research, perceived ease of use affects attitude toward using RET. However, in contrast to previous research results, Hypotheses 3b, regarding the relationship between perceived ease of use and perceived usefulness, was rejected. We speculate that this outcome was due to the division of perceived functional and economic usefulness into two constructs, which resulted in the incomplete construct of perceived usefulness. Therefore, this finding should be investigated further in future research.

Table 12. Structural relationships of constructs and testing of hypotheses with consumer data.

Hypothesis	Path	Model for Consumers	Coefficient	*t*-Value	*p*-Values
H1a	NEP → PEOU	Supported	0.520	5.214	0.000
H1b	NEP → PUF	Supported	0.318	3.208	0.001
H1c	NEP → PUE	Supported	0.237	2.215	0.027
H2a	EP → PEOU	Rejected	0.172	1.701	0.090
H2b	EP → PUF	Supported	0.392	3.976	0.000
H2c	EP → PUE	Supported	0.509	4.874	0.000
H3a	PEOU → ATU	Supported	0.296	3.159	0.002
H3b	PEOU → PUF	Rejected	0.096	1.020	0.308
H4	PUF → ATU	Supported	0.278	2.513	0.012
H5	PUE → ATU	Rejected	−0.056	0.513	0.608

Hypothesis 4 stated that PUF influenced ATU, which was supported by the results. However, somewhat surprisingly, PUE did not influence ATU, so Hypothesis 5 was rejected. This result is difficult to explain based on our research data. In previous research (e.g., [17]), economic instruments were found effective in supporting the diffusion of RET. However, in our study, this result may be due to the division of the perceived usefulness into two parts. Therefore, further research is required to determine whether the result is repeatable. Furthermore, the results of total effects analysis supported the research questions by showing that the constructs of policy influence (EP and NEP) influenced the target variable ATU through the mediating constructs of PEOU, PUF, and PUE. The total effect on attitudes was stronger in the case of the non-economic policies than in the case of the economic policies, which indicates the importance of a broad policy mix in supporting the diffusion of RET.

The results of the control group of prosumers (adopters) were very different from those of the consumers (non-adopters). The majority of the hypotheses regarding the prosumers were rejected. The TAM was designed to model technology acceptance by non-adopters. Thus, the results are in line with the theory, and they imply that prosumers expect that different types of policies support their actual use of RET.

Regarding the results of our analysis, the effect size (f^2) was large in the constructs EP on PUE (0.36) and NEP on PEOU (0.35), which indicates that both EP and NEP influence the perceptions of consumers. However, the total effect of NEP was clearly stronger than that of EP in the case of non-adopters, which indicates that it would be worthwhile for policy measures to focus on NEP rather than EP. At this stage, consumers seem to be interested in the non-economic issues associated with the adoption of RES. Thus, the motivators could be based on pro-environmental values rather than economic drivers [86]. However, consumers also seem to consider the economic policy factor in association with the economic usefulness of the RES solutions. This link could perhaps be strengthened if economic policies reflected the pricing of energy, thus making prices dependent on the energy source. In addition, economic policies could favor renewable energy and the energy stored by the prosumers. This change in economic policy to support the pricing of renewable and stored energy could attract more consumers to adopt RET because saving energy has been shown to be motivated by financial benefits more than pro-environmental values [87].

6.1. Policy Implications

Our findings suggest that the total effects of non-economic policies could shape consumers' attitudes toward using RET, even more than economic policies would. The NEP had a strong influence on PEOU and PUF. It also showed a moderate influence on PUE. However, EP also influenced PUF.

The observed non-economic policy items that were related to the regulative process of connecting RET to the grid were the awareness of tariffs and subsidies and the availability of information about energy production and usage. Based on our results, we suggest that policy makers should focus on removing regulatory barriers to allow consumers to participate actively in the energy market. Consumers have different levels of freedom to act in the energy market depending on their native country. However, in most markets, some barriers remain, hindering consumers from participating in new activities, such as energy trading and sharing in energy communities. Another observation based on the results of the study is that secured data and access to information are important to consumers. Smart grids and ICT-based solutions enable large amounts of data regarding energy consumption and production. If they are utilized well, it could help to foster consumers' acceptance as the benefits of using RET become more concrete. Consumers seem to appreciate the ability to monitor their energy use. Another observation is that energy market actors should focus on communicating information about the tariffs and the support mechanisms that are available for adopting RET.

The comparison of the results for the non-adopters and the adopters showed that the adopters were not affected by policies in the same way as the non-adopters were. Other studies, although not directly comparable with the present research, have also found indications of differences between adopter versus non-adopter attitudes (see, e.g., [88–90]). One reason for the difference in the results can be due to the different characteristics between early adopters (which majority of the RET adopters today are) and the late market adopters (see, e.g., [29]). Another explanation can be that initial policies designed to boost diffusion no longer motivate the adopters. Therefore, different policies are needed to motivate consumers' initial acceptance of RET and to support prosumers in actively continuing the use of their RETs. The finding supports the relevance of phasing out at least certain policy incentives when the diffusion has started.

6.2. Managerial Implications

We used variables related to ease of use and perceived usefulness to test the influence of policy on consumers' attitudes. Research items related to the perceived ease of use were associated with the availability of ready-to-use solutions, the availability of the solution from a one-stop-shop, and the easiness of installation. Our findings showed that these items affected the attitude toward using RET, which suggests that it is important to design turnkey solutions for RET and focus on making availability and delivery as accessible as possible for consumers.

Previous studies found that perceived usefulness was a powerful predictor of system use. In our study, perceived usefulness included functional items that were related to the availability of services that allowed monitoring and using the system, the ability to adjust the system independently, energy autonomy, information about electricity peak prices, and as a separate construct, financial benefits, such as the ability to sell excess energy for guaranteed prices. Our findings revealed that non-economic usefulness particularly affected consumers' attitudes. It is thus essential to emphasize developing and communicating the functionality benefits of RET solutions that increase the consumer's awareness of these benefits.

6.3. Limitations and Future Research

The present study has the following limitations. One limitation is related to the relatively small sample size, which was gathered across Europe, a non-homogenous area from policy, culture and economic perspectives. However, the sample size was large enough to conduct a PLS-SEM analysis on the cross-country level. Future research could however focus on conducting country level analysis of the policy implications. On the other hand, as the policies in different countries and continents can vary extensively, it would be also relevant to compare the outcome of future research in other regions to the conclusions we have made. The use of a cross-sectional design in the questionnaire is another limitation of this study. In future research, a longitudinal research approach would allow following consumer and prosumer behavior over time. Another limitation is that we utilized part of the TAM in an explorative manner: PU was divided into two parts that represented economic and functional usefulness, respectively. Furthermore, although the TAM has been proven to be a solid model for testing technology acceptance, policy interventions were not tested previously using the TAM. Hence, future research should further validate the use of the TAM when policies are considered external factors.

Our research analyzed policy instruments broadly, but there is still more room for studies on specific types of policy instruments, for example, on how policies related to information and education affect the attitudes of consumers. In future research, a more generalized conceptual framework could be developed based on our initial findings. It would also be worthwhile to study in more detail the prosumers and how to further promote and motivate RET usage among them after they have adopted RET. The identification of the possible challenges and obstacles to the usage of RET after adoption could also help to further promote RET solutions to non-adopters of RET.

7. Conclusions

Convincing consumers to contribute to international and national targets for reducing carbon emissions, improving energy efficiency, and increasing the use of RES is vital in mitigating climate change. Governments and policy makers are in the process of designing a variety of policy instruments to support the increasing consumer engagement in the energy sector. Our research focused on understanding the influence of policy on consumers' attitudes toward adopting renewable energy technologies. We approached the research problem by conducting a consumer survey. We then built the conceptual model and analyzed the data using the PLS-SEM methodology. The findings of the present study confirmed the importance of policy instruments in supporting consumers' evolution into prosumers. Our analysis of both economic and non-economic policies revealed that both could be relevant tools for the non-adopters of RET. Furthermore, our findings indicate that non-economic policies could be even more influential than economic policies are in changing consumers' attitudes toward using RET. This finding should be considered by policy makers in planning a diverse set of policies that cover a wide range of instruments.

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References

1. Bui, N.; Castellani, A.P.; Casari, P.; Zorzi, M. The internet of energy: A web-enabled smart grid system. *IEEE Netw.* **2012**, *26*, 39–45. [CrossRef]
2. International Energy Agency. *Residential Prosumers—Drivers and Policy Options (Re Prosumers)*; Renewable Energy Technology Deployment; International Energy Agency: Paris, France, 2014.
3. Toffler, A. *The Third Wave*; Williams, B., Tapscott, T., Eds.; Bantam Books: New York, NY, USA, 1981.
4. Kotler, P. Prosumers: A New Type of Consumer. *Futurist* **1986**, *20*, 24–28.
5. Ford, R.; Whitaker, J.; Stephenson, J. *Prosumer Collectives: A Review a Report for the Smart Grid Forum*; Centre for Sustainability, University of Otago: Dunedin, New Zealand, 2016.
6. Parag, Y.; Sovacool, B.K. Electricity market design for the prosumer era. *Nat. Energy* **2016**, 16032. [CrossRef]
7. Olkkonen, L.; Korjonen-Kuusipuro, K.; Grönberg, I. Redefining a stakeholder relation: Finnish energy "prosumers" as co-producers. *Environ. Innov. Soc. Transit.* **2016**. [CrossRef]
8. Bleicher, A.; Gross, M. User motivation, energy prosumers, and regional diversity: Sociological notes on using shallow geothermal energy. *Geotherm. Energy* **2015**, *3*, 12. [CrossRef]
9. Kotilainen, K.; Sommarberg, M.; Järventausta, P.; Aalto, P. Prosumer centric digital energy ecosystem framework. In Proceedings of the 8th International Conference on Management of Digital EcoSystems, Biarritz, France, 1–4 November 2016; pp. 47–51.
10. Lund, H.; Kempton, W. Integration of renewable energy into the transport and electricity sectors through V2G. *Energy Policy* **2008**, *36*, 3578–3587. [CrossRef]
11. Loisel, R.; Pasaoglu, G.; Thiel, C. Large-scale deployment of electric vehicles in Germany by 2030: An analysis of grid-to-vehicle and vehicle-to-grid concepts. *Energy Policy* **2014**, *65*, 432–443. [CrossRef]
12. Ellsworth-Krebs, K.; Reid, L. Conceptualising energy prosumption: Exploring energy production, consumption and microgeneration in Scotland, UK. *Environ. Plan. A* **2016**, *48*, 1988–2005. [CrossRef]
13. Karakaya, E.; Sriwannawit, P. Barriers to the adoption of photovoltaic systems: The state of the art. *Renew. Sustain. Energy Rev.* **2015**, *49*, 60–66. [CrossRef]
14. Davis, F.D. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q.* **1989**, *13*, 319–334. [CrossRef]
15. Kivimaa, P.; Virkamäki, V. Policy mixes, policy interplay and low carbon transitions: The case of passenger transport in Finland. *Environ. Policy Gov.* **2014**, *24*, 28–41. [CrossRef]
16. Geels, F.W. The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environ. Innov. Soc. Transit.* **2011**, *1*, 24–40. [CrossRef]
17. Vedung, E.; Bemelmans-Videc, M.L.; Rist, R.C. Policy instruments: Typologies and theories. In *Carrots, Sticks, and Sermons: Policy Instruments and Their Evaluation*; Transaction Publishers: New Brunswick, NJ, USA, 1998; pp. 21–58, ISBN 0765805464.
18. Macdonald, D. Coerciveness and the selection of environmental policy instruments. *Can. Public Adm.* **2001**, *44*, 161–187. [CrossRef]
19. Persson, Å.M. Choosing Environmental Policy Instruments: Case Studies of Municipal Waste Policy in Sweden and England. Ph.D. Dissertation, The London School of Economics and Political Science (LSE), Londen, UK, 2007.
20. Organization for Economic Co-operation and Development (OECD). *Sustainable Development—Critical Issues*; Organization for Economic Co-Operation and Development (OECD): Paris, France, 2001.
21. Coady, D.; Parry, I.; Sears, L.; Shang, B. *How Large Are Global Energy Subsidies?* International Monetary Fund: Washington DC, USA, 2015.
22. Unruh, G.C.; Carrillo-Hermosilla, J. Globalizing carbon lock-in. *Energy Policy* **2006**, *34*, 1185–1197. [CrossRef]
23. Gunningham, N. Regulation, Economic Instruments, and Sustainable Energy. In *The Handbook of Global Energy Policy*; John Wiley & Sons: New York, NY, USA, 2013; pp. 305–321, ISBN 9781118326275.
24. Rademaekers, K.; Williams, R.; Ellis, R.; Smith, M.; Svatikova, K.; Bilsen, V. *Study on Incentives Driving Improvement of Environmental Performance of Companies*; Ecorys: Rotterdam, The Netherlands, 2012.
25. Jaffe, A.B.; Stavins, R.N. Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion. *J. Environ. Econ. Manag.* **1995**, *29*, S43–S63. [CrossRef]

26. Jaffe, A.B.; Newell, R.G.; Stavins, R.N. A tale of two market failures: Technology and environmental policy. *Ecol. Econ.* **2005**, *54*, 164–174. [CrossRef]
27. Rogers, E.M. *Diffusion of Innovations*, 1st ed.; Free Press of Glencoe: New York, NY, USA, 1962.
28. Moore, G.A. *Crossing the Chasm*; Harper Business Essentials: New York, NY, USA, 1991.
29. Rogers, E.E.M. *Diffusion of Innovations*, 5th ed.; Simon&Schuster: New York, NY, USA, 2003.
30. McDaniel, P.; McLaughlin, S. Security and privacy challenges in the Smart Grid. *IEEE Secur. Priv.* **2009**, *3*, 75–77. [CrossRef]
31. Alam, S.S.; Nik Hashim, N.H.; Rashid, M.; Omar, N.A.; Ahsan, N.; Ismail, M.D. Small-scale households renewable energy usage intention: Theoretical development and empirical settings. *Renew. Energy* **2014**, *68*, 255–263. [CrossRef]
32. Burgess, J.; Nye, M. Re-materialising energy use through transparent monitoring systems. *Energy Policy* **2008**, *36*, 4454–4459. [CrossRef]
33. Darby, S. *The Effectiveness of Feedback on Energy Consumption. A Review for DEFRA of the Literature on Metering, Billing and Direct Displays*; Environmental Change Institute: Oxford, UK, 2006; Volume 22, pp. 1–21.
34. Benders, R.M.J.; Kok, R.; Moll, H.; Wiersma, G.; Noorman, K.J. New approaches for household energy conservation—In search of personal household energy budgets and energy reduction options. *Energy Policy* **2006**, *34*, 3612–3622. [CrossRef]
35. Simon, H.A. A Behavioral Model of Rational Choice. *Q. J. Econ.* **2011**, *69*, 99–118. [CrossRef]
36. Balcombe, P.; Rigby, D.; Azapagic, A. Motivations and barriers associated with adopting microgeneration energy technologies in the UK. *Renew. Sustain. Energy Rev.* **2013**, *22*, 655–666. [CrossRef]
37. Ryan, R.; Deci, E. Self-determination theory and the facilitation of intrinsic motivation. *Am. Psychol.* **2000**, *55*, 68–78. [CrossRef] [PubMed]
38. Stern, P.C.; Abel, T.D.; Stern, P.C.; Dietz, T.; Abel, T.; Guagnano, G.A.; Kalof, L. A Value-Belief-Norm Theory of Support for Social Movements: The Case of Environmentalism. *Hum. Ecol. Rev.* **1999**, *6*, 81–97. [CrossRef]
39. Fishbein, M.; Ajzen, I. *Belief, Attitude, Intention, and Behaviour: An Introduction to Theory and Research*; Addision-Wesley: Reading, MA, USA, 1975.
40. Ajzen, I. From intentions to actions: A theory of planned behavior. In *Action-Control: From Cognition to Behavior*; Beckman, J., Kuhl, J., Eds.; Springer: Heidelberg, Germany, 1985; pp. 11–39.
41. Davis, F.D.; Baggozzi, R.P.; Warshaw, P.R. Extrinsic and intrinsic motivation to use computers in the workplace. *J. Appl. Soc. Psychol.* **1992**, *22*, 1111–1132. [CrossRef]
42. Davis, F.D. A Technology Acceptance Model for Empirically Testing New End-User Information Systems: Theory and Results. Ph.D. Dissertation, Massachusetts Institute of Technology, Cambridge, MA, USA, 1986.
43. Chau, P.Y.K.; Hu, P.J. Examining a model of information technology acceptance by individual professionals: An exploratory study. *J. Manag. Inf. Syst.* **2002**, *18*, 191–229. [CrossRef]
44. Ha, S.; Stoel, L. Consumer e-shopping acceptance: Antecedents in a technology acceptance model. *J. Bus. Res.* **2009**, *62*, 565–571. [CrossRef]
45. Lu, J.; Yu, C.; Liu, C.; Yao, J.E. Technology acceptance model for wireless Internet. *Internet Res.* **2003**, *13*, 206–222. [CrossRef]
46. Ketikidis, P.; Dimitrovski, T.; Lazuras, L.; Bath, P.A. Acceptance of health information technology in health professionals: An application of the revised technology acceptance model. *Health Inform. J.* **2012**, *18*, 124–134. [CrossRef] [PubMed]
47. Naspetti, S.; Mandolesi, S.; Buysse, J.; Latvala, T.; Nicholas, P.; Padel, S.; Van Loo, E.J.; Zanoli, R. Determinants of the acceptance of sustainable production strategies among dairy farmers: Development and testing of a modified technology acceptance model. *Sustainability* **2017**, *9*, 1805. [CrossRef]
48. Chin, J.; Lin, S.C. A behavioral model of managerial perspectives regarding technology acceptance in building energy management systems. *Sustainability* **2016**, *8*, 641. [CrossRef]
49. Broman Toft, M.; Schuitema, G.; Thøgersen, J. Responsible technology acceptance: Model development and application to consumer acceptance of Smart Grid technology. *Appl. Energy* **2014**, *134*, 392–400. [CrossRef]
50. Venkatesh, V.; Morris, M.G.; Davis, G.B.; Davis, F.D. User acceptance of information technology: Toward a unified view. *MIS Q.* **2017**, *27*, 425–478. [CrossRef]
51. Kollmuss, A.; Agyeman, J. Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environ. Educ. Res.* **2002**, *8*, 239–260. [CrossRef]

52. Courtenay-Hall, P.; Rogers, L. Gaps in Mind: Problems in environmental knowledge-behaviour modelling research: Environmental Education Research. *Environ. Educ. Res.* **2002**, *8*. [CrossRef]
53. Kennedy, E.H.; Beckley, T.M.; McFarlane, B.L.; Nadeau, S. Why we don't "walk the talk": Understanding the environmental values/behaviour gap in Canada. *Hum. Ecol. Rev.* **2009**, *16*, 151–160.
54. Sheeran, P.; Abraham, C. Mediator of moderators: Temporal stability of intention and the intention-behavior relation. *Personal. Soc. Psychol. Bull.* **2003**, *29*, 205–215. [CrossRef] [PubMed]
55. Frederiks, E.R.; Stenner, K.; Hobman, E.V. Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renew. Sustain. Energy Rev.* **2015**, *41*, 1385–1394. [CrossRef]
56. Tsoutsos, T.D.; Stamboulis, Y.A. The sustainable diffusion of renewable energy technologies as an example of an innovation-focused policy. *Technovation* **2005**, *25*, 753–761. [CrossRef]
57. Faiers, A.; Neame, C. Consumer attitudes towards domestic solar power systems. *Energy Policy* **2006**, *34*, 1797–1806. [CrossRef]
58. Guardiola, S.; Gabay, G.; Moskowitz, H.R. Renewable energy; tapping and typing the citizen's mind. *Humanomics* **2009**, *25*, 254–267. [CrossRef]
59. Caird, S.; Roy, R. User-Centered Improvements to Energy Efficiency Products and Renewable Energy Systems: Research on Household Adoption and Use. *Int. J. Innov. Manag.* **2008**, *12*, 327–355. [CrossRef]
60. Sovacool, B.K. Renewable Energy: Economically Sound, Politically Difficult. *Electr. J.* **2008**, *21*, 18–29. [CrossRef]
61. Reddy, S.; Painuly, J.P. Diffusion of renewable energy technologies-barriers and stakeholders' perspectives. *Renew. Energy* **2004**, *29*, 1431–1447. [CrossRef]
62. Guy, S.; Shove, E. *A Sociology of Energy, Buildings and the Environment*; Routledge: London, UK, 2000; p. 164.
63. McKenna, E.; Richardson, I.; Thomson, M. Smart meter data: Balancing consumer privacy concerns with legitimate applications. *Energy Policy* **2012**, *41*, 807–814. [CrossRef]
64. Schleicher-Tappeser, R. How renewables will change electricity markets in the next five years. *Energy Policy* **2012**, *48*, 64–75. [CrossRef]
65. Sovacool, B.K. Rejecting renewables: The socio-technical impediments to renewable electricity in the United States. *Energy Policy* **2009**, *37*, 4500–4513. [CrossRef]
66. Palm, J.; Tengvard, M. Motives for and barriers to household adoption of small-scale production of electricity: Examples from Sweden. *Sustain. Sci. Pract. Policy* **2011**, *7*, 6–15. [CrossRef]
67. Döbelt, S.; Jung, M.; Busch, M.; Tscheligi, M. Consumers' privacy concerns and implications for a privacy preserving Smart Grid architecture—Results of an Austrian study. *Energy Res. Soc. Sci.* **2015**, *9*, 137–145. [CrossRef]
68. Schroeder, S.T.; Costa, A.; Obe, E. Support schemes and ownership structures—The policy context for fuel cell based micro-combined heat and power. *J. Power Sources* **2011**, *196*, 9051–9057. [CrossRef]
69. Caird, S.; Roy, R. Adoption and Use of Household Microgeneration Heat Technologies. *Low Carbon Econ.* **2010**, *1*, 61–70. [CrossRef]
70. Michaels, L.; Parag, Y. Motivations and barriers to integrating "prosuming" services into the future decentralized electricity grid: Findings from Israel. *Energy Res. Soc. Sci.* **2016**, *21*, 70–83. [CrossRef]
71. Islam, T.; Meade, N. The impact of attribute preferences on adoption timing: The case of photo-voltaic (PV) solar cells for household electricity generation. *Energy Policy* **2013**, *55*, 521–530. [CrossRef]
72. Leenheer, J.; de Nooij, M.; Sheikh, O. Own power: Motives of having electricity without the energy company. *Energy Policy* **2011**, *39*, 5621–5629. [CrossRef]
73. Hansla, A.; Gamble, A.; Juliusson, A.; Gärling, T. Psychological determinants of attitude towards and willingness to pay for green electricity. *Energy Policy* **2008**, *36*, 768–774. [CrossRef]
74. Venkatesh, V.; Bala, H. Technology acceptance model 3 and a research agenda on interventions. *Decis. Sci.* **2008**, *39*, 273–315. [CrossRef]
75. Sternad, S.; Bobek, S. Impacts of TAM-based External Factors on ERP Acceptance. *Procedia Technol.* **2013**, *9*, 33–42. [CrossRef]
76. Surendran, P. Technology Acceptance Model: A Survey of Literature. *Int. J. Bus. Soc. Res.* **2012**, *2*, 175–178. [CrossRef]
77. Huijts, N.M.A.; Molin, E.J.E.; Steg, L. Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. *Renew. Sustain. Energy Rev.* **2012**, *16*, 525–531. [CrossRef]

78. Hair, J.F., Jr.; Hult, G.T.M.; Ringle, C.; Sarstedt, M. *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*; Sage Publications: London, UK, 2016.
79. Joe, F., Jr.; Sarstedt, M.; Hopkins, L.; Kuppelwieser, V.G. Partial least squares structural equation modeling (PLS-SEM): An emerging tool in business research. *Eur. Bus. Rev.* **2014**, *26*, 106–121. [CrossRef]
80. Bentler, P.M. SEM with simplicity and accuracy. *J. Consum. Psychol.* **2010**, *20*, 215–220. [CrossRef] [PubMed]
81. Nishimura, R.; Wagner, J.; Elliott, M. Alternative Indicators for the Risk of Non-response Bias: A Simulation Study. *Int. Stat. Rev.* **2016**, *84*, 43–62. [CrossRef] [PubMed]
82. Janssens, W.; Wijnen, K.; De Pelsmacker, P.; van Kenhove, P. *Marketing Research with SPSS*; Pearson Education Limited: Essex, UK, 2008.
83. Fornell, C.; Larcker, D.F. Evaluating structural equation models with unobservable variables and measurements error. *J. Mark. Res.* **1981**, *18*, 39–50. [CrossRef]
84. Hair, J.F.; Black, W.C.; Babin, B.J.; Anderson, R.E. *Multivariate Data Analysis: A Global Perspective*; Prentice Hall: Upper Saddle River, NJ, USA, 2010; ISBN 9780135153093.
85. Henseler, J.; Ringle, C.M.; Sarstedt, M. A new criterion for assessing discriminant validity in variance-based structural equation modeling. *J. Acad. Mark. Sci.* **2014**, *43*, 115–135. [CrossRef]
86. Stern, P.C. Toward a Coherent Theory of Environmentally Significant Behavior. *J. Soc. Issues* **2000**, *56*, 407–424. [CrossRef]
87. Whitmarsh, L.; O'Neill, S. Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *J. Environ. Psychol.* **2010**, *30*, 305–314. [CrossRef]
88. Zhai, P.; Williams, E.D. Analyzing consumer acceptance of photovoltaics (PV) using fuzzy logic model. *Renew. Energy* **2012**, *41*, 350–357. [CrossRef]
89. Ozdemir, S.; Trott, P. Exploring the adoption of a service innovation: A study of Internet banking adopters and non-adopters. *J. Financ. Serv. Mark.* **2009**, *13*, 284–299. [CrossRef]
90. Sopha, B.M.; Klöckner, C.A.; Hertwich, E.G. Adopters and non-adopters of wood pellet heating in Norwegian households. *Biomass Bioenergy* **2011**, *35*, 652–662. [CrossRef]

PUBLICATION
VI

Sustainable electric vehicle-prosumer framework and policy mix

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Sustainable Electric Vehicle – Prosumer Framework and Policy Mix

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***Abstract*— Electric vehicles have pro-environmental advantages compared to traditional automobiles, or even hybrids: they can help reducing pollution and noise levels locally, and greenhouse gas emissions globally. However, there are still many challenges that the electric vehicles must overcome before reaching level of diffusion that can have significant impact on sustainability. This paper evaluates combined sustainability of electric vehicle and small-scale energy production. We propose a framework for sustainable electric vehicle – energy prosumer integration and outline a policy mix that is needed to support adoption of both renewable energy technologies and electric vehicles.**

***Index Terms*—Renewable energy, electric vehicle, prosumer, sustainable, policy**

I. Introduction

Climate change and growing need for energy are forcing policy makers to address how to accelerate adoption of environmentally sustainable products and services. Technology developments in renewable energy generation equipment, smart power grids and transportation solutions all enable new innovative ways for consumers to participate in sustainability transition taking place in various industries. Energy and transportation together contribute 49 % of greenhouse gases emitted to the atmosphere [1]. With solar photo voltaic (PV) becoming affordable for households, more and more energy consumers are evolving into energy prosumers i.e. producers and consumers of energy. Electric vehicles (EV), either battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV) (see e.g. [2]), have been suggested as one solution leading to sustainable development of energy system as a whole through using renewable energy sources (RES) and vehicle to grid (V2G) integration. However, socio-technical barriers such as perceived uncertainty in addition to performance issues related to battery range and cost [3], charging interoperability, taxation policies [4], and lack of awareness of governmental incentive programs [5] are slowing down consumer adoption of EVs. Local renewable energy sources (RES) and EVs together could be a way towards minimizing emissions and using the electricity system in an efficient way. Hence, in order to steer the development into the right path, governmental interventions are seen as vital to ensure wide scale adoption of green innovations (e.g. [6]).

The paper has been structured as follows: Firstly, we review theoretical framework for the socio-technical transitions taking place at transportation and energy sectors and assess policies and incentives that are available for sustainable innovations. Secondly, we introduce the research approach followed by introduction of a framework for sustainable EV-Prosumer interactions and mapping of policies that support the framework. Lastly, discussion section summarizes the policy implications and proposes agenda items for future research.

II. Theoretical Review

A. *Socio-technical multilevel perspective – energy and trasportation sector transitions*

Systemic changes, like shift to EVs, do not happen easily. They require profound changes in products, services and technologies around the new innovation. Transition Management (TM) and Multi-level perspective (MLP) are common frameworks for analyzing such industry transitions [7]. TM refers to an approach to steer long-term changes that take place in socio-technical systems. Industry transitions should be governed bottom-up with experimental approaches and explicitly designing processes for learning-by-doing.

MLP considers transitions at different interlinked levels of socio-technical systems. Central dynamics take place between niche players in micro level and present regimes on meso level. Niches, the bottom layer, are legally or otherwise protected spaces where new radical innovations and technologies can develop. Landscape, the top layer, is global in its nature and refers to social values, institutions and beliefs of society broadly. For a meso-level regime transition to happen there has to be pressure from both, the upper landscape and the lower niche levels. There is no uniform definition for socio-technical regimes and in some cases, regimes can be used as synonyms to markets or sectors [8]. Regimes are also multi-dimensional including dimensions like user practices, policy issues, knowledge and infrastructure.

The socio-technical framework is useful for energy sector as it can be used to analyze dynamics between new and incumbent players and their objectives. For example, Geels [9] investigated

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how regime mechanisms can stabilize the development of niches. Furthermore, legacies, like earlier investments in large production sites and grids, create path dependencies and lock-ins. These aspects are important in the MLP framework because they create stabilizing forces that keep the regime level in power [10], [11].

B. Diffusion of innovations

Diffusion of innovation is a process describing spread of innovations over time [12]; different adopter groups take new innovation into use on progressive order. The first adopters are the innovators, who are most often technology enthusiasts that can tolerate products with complexity and are not very sensitive to costs. The next adopter group is the early adopters that could be interested in the new technology solution due to a special need or to impress their peers. The early adopters often wish to be opinion leaders and like to recommend products. They also may have strong pro-environmental reasons to adopt new technologies early. Once the early market adoption takes off properly, late market adopters, including early majority, late majority and the laggards, can be reached. The late market, or mass market, adopters usually expect ease of use, good value for money and clear benefits.

Prosumer adoption of RES varies largely by market. Solar PV price levels have dropped globally and the energy production is becoming more affordable for small scale producers. Some governments have launched attractive economic incentives to further boost solar PV adoption and this has caused fast diffusion in Germany, for example. Nevertheless, prosumer adoption of RES is in the early market phase in most markets. EVs particularly are currently in the early market phase; the global average market share being mere 0.2% of the total passenger light duty vehicle circulation stock worldwide [13]. Some of the countries are further ahead; Norway is the leading market for EV adoption with sales market share of 29% (combined BEV and PHEV in 2016) followed by the Netherlands (6.4 %). China, France and United Kingdom have sales market share of 1.5%. China and the United states are clear leaders in the EV volumes. In 2016 there were 750 thousand new EV registrations and the total vehicle stock was ca. 2 million [13].

C. Policies to support diffusion of sustainable technologies

Policy support is commonly seen as critical accelerator of environmentally sustainable innovations. Environmental policy instruments (EPI) have been a center of interest in European countries where innovative policies have been introduced to complement traditional regulation to achieve environmental goals. Basic public policy instruments can be divided to regulatory instruments, financial instruments and information transfer (e.g. [14]). There are several ways to categorize EPIs in more detail. For example, OECD [15] has used: command and control, economic instruments, liability and damage compensation, education and information, voluntary approaches (VA) and management and planning. A simpler way to describe different types of EPIs is to refer to them as “market based” or “command and control” (or “regulatory”). Additionally, level of coerciveness, or intrusiveness, is often used to categorize EPIs (e.g. [16]).

Policy cycle phase affects to the policy instrument choice. The key policy phases are: 1) agenda-setting, 2) policy formulation, 3) policy decision-making, 4) policy implementation, and 5) policy evaluation [17]. As EVs are in the early phase and governments are still evaluating possible EPI options, many of the instruments have been designed to boost the EV adoption [4] by economic means. Once the adoption reaches desired level and EVs are able to be self-sufficient, most of the economic instruments will be phased out. Development of micro-generation policies in energy markets are ahead of EVs and energy policies have stabilized to some extent, albeit they are in a flux as the results of the interventions are observed and corrective moves made [18]. EV policies should continue to concentrate on early adoption and early markets rather than mass markets [19] as this has more impact on the increasing adoption of the EVs. Recent studies also show that EV policies do indeed influence propensity to purchase EVs in addition to socio-psychological determinants [20].

III. RESEARCH APPROACH

EV sustainability largely depends on whether emission free energy sources are used to power up the vehicles. We are interested in exploring how microgeneration (based on RES), by small scale energy prosumers, and EVs (in particular BEVs) together can increase sustainability of the energy system (Research Question (RQ) 1) and what kind of policy mix would be required to support the combined EV – Prosumer activity (RQ2). Our approach is to assess EV and Prosumer related technologies, sustainability factors, adoption challenges and policies. As a conclusion, we propose a sustainable EV – Prosumer (SEP) framework and outline a policy mix to support it.

The SEP framework must fulfil two core requirements. Firstly, the framework must be based on combined sustainability impacts of both EVs and small-scale energy production by prosumers (i.e. prosumption). Hence, we present short analysis of EV and prosumption benefits and challenges and highlight the sustainability aspects of both. Secondly, both EV and prosumer market share must rise to a level required to have impact on the overall sustainability of energy and transportation systems. Policy support is critical in accelerating the adoption of new environmentally sustainable technologies. We will thus assess both EV policy options and prosumer support options that together are necessary to sustainability of the SEP framework.

A. EV sustainability benefits and challenges

Sustainability of EVs has been under constant debate. It is widely accepted that the main EV sustainability benefits are reduction of local emissions and noise levels as well as overall reduction of CO_2 emissions in case the electricity used to charge the EV batteries is generated based on RES.

EV’s are facing multiple challenges in terms of consumer acceptance. BEV availability in car manufacturer portfolios has been limited; consumers do not find the type of vehicle they would like to buy and thus opt for a vehicle with an internal combustion engine (ICE). Price gap between EV initial purchase price and a comparable ICE vehicle is still considerable. Even though maintenance and use is less expensive, the initial capital expenditure is preventing many consumers from making the decision to buy an EV. Battery price levels are dropping as the volumes grow, but the battery price is still the main cost differentiator for EVs. There are also usability issues; current EV driving range (up to 300-400 km) is seen as limiting, charging times for EVs are perceived as too long and charging infrastructure (especially smart chargers and fast chargers) is in its infancy. Developing better solutions for charging is important as consumers feel uncomfortable about acquiring a vehicle that they may not be able to charge when needed, outside their home.

B. DER/microgeneration benefits and challenges

Emission free energy generation using RES is the most obvious sustainability benefit of prosumption. Energy produced is free of charge (unless charges are posed through regulation) and excess energy can be stored in external batteries (e.g. EV batteries). Demand response (DR) schemes are developed to better integrate energy users to the energy system through balancing consumption from peak to non-peak hours. Distributed energy resources (DER) bring much needed flexibility to the energy production and if spread widely, can have an impact on the global emission reduction.

On the other hand, energy regime incumbent actors have many concerns over increased DER/microgeneration. Variable energy generation can be difficult to predict and does not fit in optimal way to the current energy market processes. There are concerns that small-scale distributed energy resources (DER) can challenge the power grid stability. If not planned, built and managed professionally, energy communities and micro-grids could cause severe problems to the electricity system. Even an "off grid phenomenon" can take place in case enough prosumers decide to rely on self-generation. This could happen in case the prosumers are able to generate enough energy to be self-sufficient or the national energy price levels become too high.

C. EV, DER and DR policies

Economic instruments have been found to be essential to boost adoption of new technologies, albeit other incentives are also important. However, there is consensus among experts and policy makers that once the diffusion reaches mass markets, economic instruments should be phased out. Table 1 maps policies to EVs, microgeneration and demand response (DR).

The categories (in Table 1) vary from regulatory through market based approaches to voluntary approaches. The policies are relevant from socio-technical MLP: most of the command and control policies are driven from landscape (macro) level (e.g. EU directives) to influence the system while innovative voluntary approaches and self-regulations can emerge bottom up from micro (niche) level.

There are multiple macro level policy instruments that are dominating the DR and microgeneration possibilities and attractiveness [21]–[23]. EV policies on the other hand are more market based than DER/microgeneration policies and, if they exist at all, are currently designed to boost EV adoption. Many governments are still very much in the agenda-setting phase related to EV policies.

TABLE I. SUMMARY OF EV AND DER RELATED POLICIES

EPI policy type	**Electric vehicles** [13]	**Microgeneration** [23],[21],[22]	**Demand response** [24],[25],[26],[27]
Regulatory	Permit use of bus lanes Building codes and permits Tailpipe emission standards	Building codes Interconnection rules Self-consumption Collective self-consumption Priority dispatch System size limitations Smart meter rollout Third party ownership Certificates on technology and installations CO2 emission restrictions (e.g. Kyoto protocol, EU-ETS) Restriction on product energy consumption (e.g. power limits)	Building codes and regulation on electrical installations Allowing market entrance for DR and aggregated load Product requirements like minimum bid sizes and duration Communication standards and protocols Performance measurement Smart meter rollout Data protection Revising DSO regulation
Economic	CO2 tailpipe tax Exempt from purhase tax, VAT Exempt from usage tax Subsidy on purchase price Exempt from roadtolls	Exempt from self-generation tax Tax credits Reduced VAT Interconnection fees Network tariffs Self-consumption fees Investment subsidies Soft loans Feed in tariffs and premiums Net metering and billing	Dynamic pricing Capacity based network charges Dynamic taxes Avoiding fixed levies in electricity prices Penalties and financing requirements for aggregators
Management and planning	Investment in charging infrastructure R&D investments in battery technology development	Micro-grid management Balancing rules and responsibilities	Balancing rules and responsibilities Local flexibility trading Data manangement
Information, education and other	Free parking for EVs Information and education campaigns Public use of EVs Lead users for EVs	Eco-labeling Energy saving campaigns Demonstrations	Smart home labels Demonstrations Campaigns and education Regulation on information about the contract Standardising contract types
Voluntary agreements	EV clubs and associations Use of alternative transportation	Shareholder programs Green tariffs Energy saving (e.g. LED lights)	

IV. SUSTAINABLE EV-PROSUMER (SEP) FRAMEWORK AND POLICY MIX

As described above, EV sustainability is noticeably enhanced when *renewable energy sources* are used to charge the EV battery and EV is connected to power grid and can be used for *demand respons*e, through vehicle to grid (V2G) connection, and to balance peak-off peak consumption. Furthermore, sustainability benefits from the DER and prosumption are based on energy generation using emission free renewable energy sources, increased *energy efficiency* and participation in demand response schemes, that can further be enhanced by introducing *energy storage* (battery or EV) and *smart metering.*

The SEP framework presented in Figure 1 describes energy prosumer centric microgeneration based on solar PV and using batteries and EVs as energy storage. The framework includes grid connection for both EV and solar PV / battery storage.

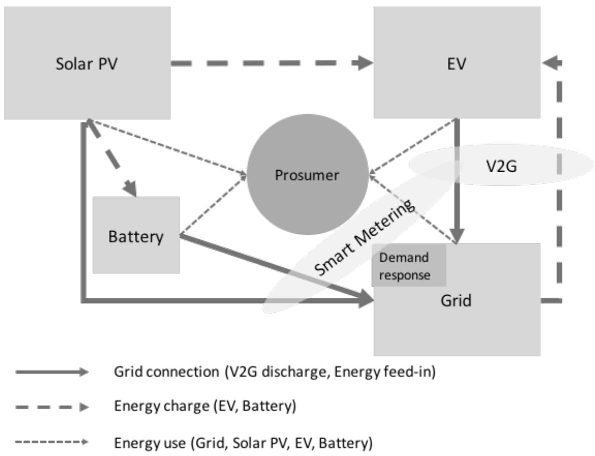

Figure 1. Sustainable EV – Prosumer (SEP) Framework

Figure 2 summarizes policy mix support requirements for SEP framework. Policy instruments cover EV policy instruments and DER/microgeneration policy instruments. In short, the policy instrumets to push SEP as the preferred way to produce, store and use energy must be supporting a) adoption of EVs, batteries, smart meters and solar PV, b) enable grid and V2G connections and c) incentivice participation in DR schemes.

Self-generation of energy must be promoted and incentivized and prosumers need to be encouraged to connect their batteries and EVs to the power grid and participate in demand response schemes. Policy mix for SEP should include at least support for technology adoption of at least solar PV, EVs, and smart meters. This can be achieved through market based policy instruments that incentivice purchase decision of EVs or solar PV. In addition, regulative instruments including changes in legislation are needed to ensure availability of smart metering in residential buildings and enable small scale producer's grid connection. Continuous R&D investments are still required for charging technology and infrastructure development and battery technology development. Information campaigns and education can help reducing EV related concerns and misconceptions.

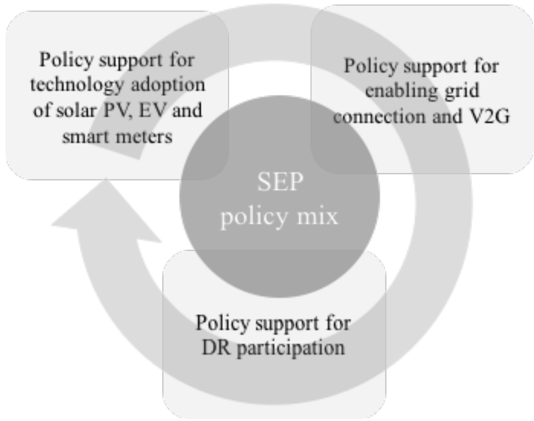

Figure 2. SEP policy mix

EVs require similar kind of dedicated grid connection requirements, which have enabled solar PV diffusion. A non-discriminatory access to electricity network is needed and standards and communication protocols for charging stations have to be defined. Charging station deployment targets and building codes with minimum charging station mandates ensure that enough EV parking spaces are built. Property laws should be changed so that especially housing companies can easier deploy charging sations. Many countries have also introduced financial incentives for them, which further accelerates their diffusion [13].

Prosumer-level DR requires regulation that opens the electricty market for new end-user business models. Smart meter rollout is the first step. The market needs to be opened to new independent actors like aggregators. For further deployment, aggregation requires standardised products, customer's better access to data, small enough bids to get into the electricity market and protection of consumer privacy [23],[24]. Introduction of advanced pricing schemes, like Time-of-Use pricing or real-time pricing would incentivise consumers to change their consumption patterns. Network tariff structures are being re-designed away from volumetric rates to enable bi-directional electricity flows. Yet, tariff design has to be done carefully so that DR and self-consumption are not overly discouraged by fixed tariff rates. Also, DSOs' remuneration models should incentivise acquiring flexibility services [25]. Consumers should be well informed of their contract options and the system benefits they can bring.

V. DISCUSSION

SEP framework is based on combined sustainability benefits of EVs and DER/Microgeneration. The framework positions the prosumer, i.e. a small energy customer-producer, in the focal point and proposes that by accelerating the adoption of microgeneration technologies (such as solar PV), Smart Meters, EVs and V2G and at the same time taking a systemic approach to policy mix design, the combined sustainability impacts of the system can be extended.

When comparing EV and DER/microgeneration policies, it is evitable that EV policies are less regulative than the DER/microgeneration policies. EV push is based heavily on taxation and market based economic instruments as well as on information and education. DER/microgeneration on the other has a lot of command and control type of regulations that are related to emission restrictions of energy generation, trading and ensuring security of energy supply and keeping the power grid stable.

The SEP framework provides an integrated view on the succession of different policy instruments and their effects in general level. As such, it provides multiple avenues for future research. For example, how impact of policies can be measured in an integrated way, what are the multi-policy selection spaces that are feasible and how they are forming in difference phases of evolution. Also, based on the SEP framework it is possible to conceptualize various sustainability paths based on alternating multi-policy instruments targeting multiple impacts.

Novelty value of the paper lies not so much on the SEP framework alone, but rather on the mapping of a possible policy mix that can support the combination of sustainable energy production by small scale producers and EVs. There is earlier and ongoing research on EVs, V2G, DER and DR, however, the research lags behind in integrated policy mixes that are needed to ensure that the benefits of technology development are fully exploited and to maximize consumer value proposition for sustainable technology adoption. Policy makers should focus on more systemic approach when designing policy instruments and find policy synergies to better support sustainability transition that is taking place concurrently in multiple sectors.

REFERENCES

[1] "Climate Change 2014–Impacts, Adaptation and Vulnerability: Regional Aspects."

[2] T. H. Bradley and A. A. Frank, "Design, demonstrations and sustainability impact assessments for plug-in hybrid electric vehicles," *Renew. Sustain. Energy Rev.*, vol. 13, no. 1, pp. 115–128, 2009.

[3] O. Egbue and S. Long, "Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions," *Energy Policy*, vol. 48, pp. 717–729, 2012.

[4] G. Haddadian, M. Khodayar, and M. Shahidehpour, "Accelerating the global adoption of electric vehicles: barriers and drivers," *Electr. J.*, vol. 28, no. 10, pp. 53–68, 2015.

[5] R. M. Krause, S. R. Carley, B. W. Lane, and J. D. Graham, "Perception and reality: Public knowledge of plug-in electric vehicles in 21 US cities," *Energy Policy*, vol. 63, pp. 433–440, 2013.

[6] K. S. Gallagher and E. Muehlegger, "Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology," *J. Environ. Econ. Manage.*, vol. 61, no. 1, pp. 1–15, 2011.

[7] U. Pesch, "Tracing Discursive Space: Agency and Change in Sustainability Transitions," *Technol. Forecast. Soc. Change*, no. 90, pp. 379–388, 2015.

[8] J. Markard and B. Truffer, "Technological innovation systems and the multi-level perspective: Towards an integrated framework," *Res. Policy*, vol. 37, no. 4, pp. 596–615, 2008.

[9] F. W. Geels, "Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective," *Theory, Cult. Soc.*, no. May 2013, p. 0263276414531627-, 2014.

[10] J. Foxon, T. J., Pearson, P. J., Arapostathis, S., Carlsson-Hyslop, A., & Thornton, "Branching points for transition pathways: assessing responses of actors to challenges on pathways to a low carbon future," *Energy Policy*, no. 52, pp. 146–158, 2013.

[11] K. Kotilainen, M. Sommarberg, P. Järventausta, and P. Aalto, "Prosumer centric digital energy ecosystem framework," *Proc. 8th Int. Conf. Manag. Digit. Ecosyst. - MEDES*, pp. 47–51, 2016.

[12] E. M. Rogers, *Diffusion of Innovations (first edition).*, 1st ed. Free Press of Glencoe, 1962.

[13] "Global EV Outlook 2017 Two million and counting," 2017.

[14] E. Vedung, M. L. Bemelmans-Videc, and R. C. Rist, "Policy instruments: typologies and theories.Carrots, sticks, and sermons: Policy instruments and their evaluation," *Carrots, sticks, sermons Policy instruments their Eval.*, vol. 5, 1998.

[15] OECD, *Sustainable development - critical issues*. OECD, 2001.

[16] D. Macdonald, "Coerciveness and the selection of environmental policy instruments," *Can. Public Adm.*, vol. 44, no. 2, pp. 161–187, 2001.

[17] M. Howlett and M. Ramesh, "Studying Public Policy: Policy cycles and policy subsystems.," 2003.

[18] G. Simpson and J. Clifton, "The emperor and the cowboys: The role of government policy and industry in the adoption of domestic solar microgeneration systems," *Energy Policy*, vol. 81, pp. 141–151, 2015.

[19] E. H. Green, S. J. Skerlos, and J. J. Winebrake, "Increasing electric vehicle policy efficiency and effectiveness by reducing mainstream market bias," *Energy Policy*, vol. 65, pp. 562–566, 2014.

[20] J. H. M. Langbroek, J. P. Franklin, and Y. O. Susilo, "The effect of policy incentives on electric vehicle adoption," *Energy Policy*, vol. 94, pp. 94–103, 2016.

[21] K. Veum *et al.*, "Mainstreaming RES," Amsterdam, 2016.

[22] IEA-PVPS, *Review and analysis of pv self-consumption policies*. 2016.

[23] International Energy Agency, "Residential prosumers – drivers and policy options (RE prosumers)," *Renew. Energy Technol. Deploy.*, no. June, 2014.

[24] SEDC, "Explicit Demand Response in Europe: Mapping the Markets," 2017.

[25] M. Valles, J. Reneses, R. Cossent, and P. Frias, "Regulatory and market barriers to the realization of demand response in electricity distribution networks: A European perspective," *Electr. Power Syst. Res.*, vol. 140, pp. 689–698, 2016.

[26] K. Knezović, M. Marinelli, A. Zecchino, P. B. Andersen, and C. Traeholt, "Supporting involvement of electric vehicles in distribution grids: Lowering the

barriers for a proactive integration," *Energy*, vol. 134, pp. 458–468, 2017.
[27] THEMA Consulting Group, *Demand response in the Nordic electricity market*. Nordic Council of Ministers, 2014.
[28] SEDC, "Empowering Residential and SME Consumers," no. October, 2016.