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Socio-economic conditions for satisfying human needs at low energy use: An international analysis of social provisioning

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ABSTRACT

Meeting human needs at sustainable levels of energy use is fundamental for avoiding catastrophic climate change and securing the well-being of all people. In the current political-economic regime, no country does so. Here, we assess which socio-economic conditions might enable societies to satisfy human needs at low energy use, to reconcile human well-being with climate mitigation.

Using a novel analytical framework alongside a novel multivariate regression-based moderation approach and data for 106 countries, we analyse how the relationship between energy use and six dimensions of human need satisfaction varies with a wide range of socio-economic factors relevant to the provisioning of goods and services ('provisioning factors'). We find that factors such as public service quality, income equality, democracy, and electricity access are associated with higher need satisfaction and lower energy requirements ('beneficial provisioning factors'). Conversely, extractivism and economic growth beyond moderate levels of affluence are associated with lower need satisfaction and greater energy requirements ('detrimental provisioning factors'). Our results suggest that improving beneficial provisioning factors and abandoning detrimental ones could enable countries to provide sufficient need satisfaction at much lower, ecologically sustainable levels of energy use.

However, as key pillars of the required changes in provisioning run contrary to the dominant political-economic regime, a broader transformation of the economic system may be required to prioritise, and organise provisioning for, the satisfaction of human needs at low energy use.

1. Introduction

Limiting global warming to 1.5 °C without relying on negative emissions technologies requires not only rapid decarbonisation of global energy systems but also deep reductions in global energy use (Grubler et al., 2018; IPCC, 2018). At the same time, billions of people around the globe are still deprived of basic needs, and current routes to sufficient need satisfaction all seem to involve highly unsustainable levels of resource use (O'Neill et al., 2018). The way societies design their economies thus seems misaligned with the twin goals of meeting everyone's needs and remaining within planetary boundaries (O'Neill et al., 2018; Raworth, 2017). This study addresses this issue by empirically assessing how the relationship between energy use and need satisfaction varies with the configurations of key socio-economic factors, and what configurations of these factors might enable societies to meet human needs within sustainable levels of energy use.

While these questions are poorly understood and empirically understudied (Brand Correa and Steinberger, 2017; Lamb and Steinberger, 2017; O'Neill et al., 2018; Roberts et al., 2020), the corner pieces of the research puzzle are largely in place. We roughly know the maximum level of final energy use (~27 GJ/cap) that can be globally rendered ecologically 'sustainable' (compatible with avoiding 1.5 °C of global warming without relying on negative emissions technologies) with deep transformations of energy systems (Grubler et al., 2018; IPCC, 2018). We understand what defines and characterises human needs, and what levels of which goods, services and conditions generally satisfy these needs (Doyal and Gough, 1991; Max-Neef, 1991; Millward-Hopkins et al., 2020; Rao and Min, 2018a).

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We also know the basic characteristics of the cross-country relationship between energy use and a wide range of needs satisfaction indicators, including life expectancy, mortality, nourishment, education, and access to sanitation and drinking water (Burke, 2020; Lambert et al., 2014; Mazur and Rosa, 1974; Rao et al., 2014; Steinberger and Roberts, 2010). While at low levels of energy use, these need satisfaction indicators strongly improve with increasing energy use, they generally saturate at internationally moderate levels of energy use (ibid.). Beyond that saturation level, need satisfaction improvements with additional energy use quickly diminish, reflecting the satiability of needs (Doyal and Gough, 1991).

How much energy use is required to provide sufficient need satisfaction is only scarcely researched, and the few existing estimates are broadly scattered (Rao et al., 2019). Empirical cross-national estimates include 25–40 GJ/cap primary energy use for life expectancy and literacy (Steinberger and Roberts, 2010), or 22–58 GJ/cap final energy use for life expectancy and composite basic needs access (Lamb and Rao, 2015). Empirically-driven bottom-up model studies estimate the final energy footprints of sufficient need satisfaction in India, South Africa and Brazil to range between 12 and 25 GJ/cap (Rao et al., 2019), based on Rao and Min's (2018a) definition of 'Decent Living Standards' that meet human needs. Global bottom-up modelling studies involving stronger assumptions of technological efficiency and equity, respectively, suggest that by 2050, Decent Living Standards could be internationally provided with 27 GJ/cap (Grubler et al., 2018) or even just 13–18 GJ/cap final energy use (Millward-Hopkins et al., 2020). Together, these studies demonstrate that meeting everyone's needs at sustainable levels of energy use is theoretically feasible with known technology.

What remains poorly understood, however, is how the relationship between human need satisfaction and energy use (or biophysical resource use) varies with different socio-economic factors (Lamb and Steinberger, 2017; O'Neill et al., 2018; Steinberger et al., 2020). A small number of studies offer initial insights. The environmental efficiency of life satisfaction, presented as a measure of *sustainability*, follows an inverted-U-shape with Gross Domestic Product (GDP), increases with trust, and decreases with income inequality (Knight and Rosa, 2011). The carbon or environmental intensities of life expectancy, understood as measures of *unsustainability*, increase with income inequality (Jorgenson, 2015), urbanisation (McGee et al., 2017) and world society integration (Givens, 2017). They furthermore follow a U-shape with GDP internationally (Dietz et al., 2012), though increasing with GDP in all regions but Africa (Jorgenson, 2014; Jorgenson and Givens, 2015), and show asymmetric relationships with economic growth and recession in 'developed' vs. 'less developed' countries (Greiner and McGee, 2020). Their associations with uneven trade integration and exchange vary with levels of development (Givens, 2018). Democracy is not significantly correlated with the environmental efficiency of life satisfaction (Knight and Rosa, 2011) nor with the energy intensity of life expectancy (Mayer, 2017). All of these studies either combine need satisfaction *outcomes from* societal activity and biophysical *means to* societal activity into a *ratio* metric, or analyse residuals from their regression. Hence, they do not specify how these socio-economic factors interact with the highly non-linear *relationship* between need satisfaction and biophysical resource use, or with the ability of countries to reach targets simultaneously for need satisfaction and energy (or resource) use.

The socio-economic conditions for satisfying human needs at low energy use have been highlighted as crucial areas of research (Brand Correa and Steinberger, 2017; Lamb and Steinberger, 2017; O'Neill et al., 2018; Roberts et al., 2020), but remain virtually unstudied. While the theoretical understanding of this issue has seen important advances (Bohnenberger, 2020; Hickel, 2020; Stratford, 2020; Stratford and O'Neill, 2020; Gough, 2017; Kallis et al., 2020; Parrique, 2019), empirical studies are almost entirely absent. Lamb (2016a, 2016b) qualitatively discusses socio-economic factors in enabling low-energy (or low-carbon) development, but only for a small number of countries. Furthermore, Lamb et al. (2014) explore the cross-country relationship between life expectancy and carbon emissions in light of socio-economic drivers of emissions, but do not quantitatively assess how life expectancy is related to carbon emissions nor to socio-economic emissions drivers. Quantitative empirical cross-country analyses of the issue thus remain entirely absent.

We address these research gaps by making three contributions. First, we develop a novel analytical approach for empirically assessing the role of socio-economic factors as *intermediaries moderating the relationship* between energy use (as a *means*) and need satisfaction (as an *end*), thus analytically separating means, ends and intermediaries (Fig. 1). For this purpose, we adapt and operationalise a novel analytical framework proposed by O'Neill et al. (2018) which centres on provisioning systems as intermediaries between biophysical resource use and human well-being (Fig. 1A). Second, we apply this approach and framework for the first time, using data for 19 indicators and 106 countries to empirically analyse how the relationships between energy use and six dimensions of human need satisfaction vary with a range of political, economic, geographic and infrastructural 'provisioning factors' (Fig. 1B). Third, we assess which socio-economic conditions (i.e. which configurations of provisioning factors) might enable countries to provide sufficient need satisfaction within sustainable levels of energy use. Specifically, we address the following research questions:

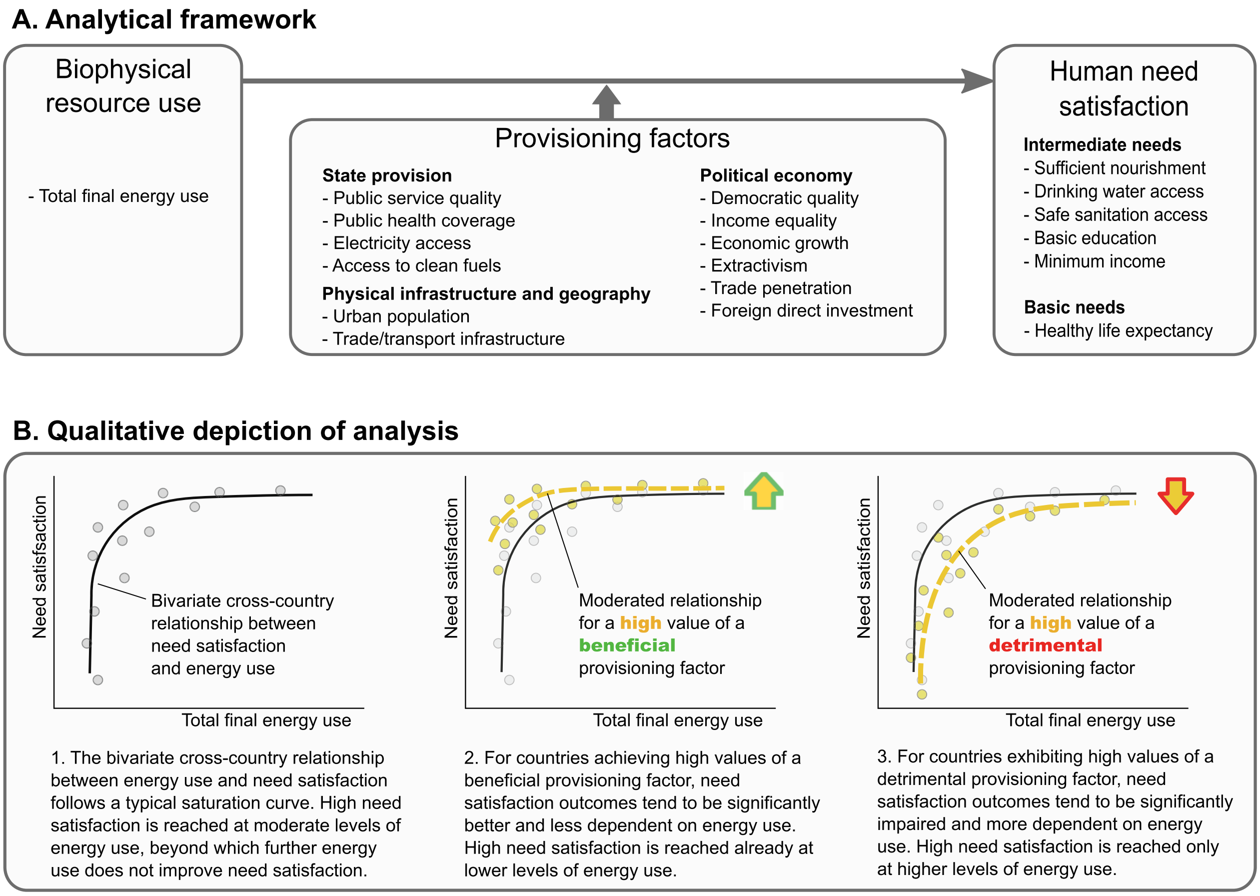
1) What levels of energy use are associated with sufficient need satisfaction in the current international provisioning regime?
2) How does the relationship between energy use and human need satisfaction vary with the configurations of different provisioning factors?
3) Which configurations of provisioning factors are associated with *socio-ecologically beneficial performance* (higher achievements in, and lower energy requirements of, human need satisfaction), and which ones are associated with *socio-ecologically detrimental performance* (lower achievements in, and greater energy requirements of, need satisfaction)?
4) To what extent could countries with beneficial configurations of key provisioning factors achieve sufficient need satisfaction within sustainable levels of energy use?

The remainder of this article is structured as follows. We introduce our analytical framework and outline our analytical approach in Section 2. We describe our variables and data in Section 3, and detail our methods in Section 4. We present the results of our analysis in Section 5, and discuss them in Section 6. We summarise and conclude our analysis in Section 7.

2. Analytical framework and approach

Building on the work of O'Neill et al. (2018), our analytical framework (Fig. 1A) conceptualises the provisioning of human needs satisfaction in an Ends–Means spectrum (Daly, 1973). Our framework considers energy use as a means, and need satisfaction as an end, with provisioning factors as intermediaries that moderate the relationship between means and ends. We thus operationalise O'Neill et al.'s (2018) framework by reducing the sphere of biophysical resource use to energy use (for analytical focus), and reducing the sphere of human well-being to human need satisfaction (for analytical coherence). Our operationalisation of human need satisfaction follows Doyal and Gough's (1991) *Theory of Human Need*, reflecting a eudaimonic understanding of well-being as *enabled by* the satisfaction of human needs, which can be evaluated based on objective measures (Brand Correa and Steinberger, 2017; Lamb and Steinberger, 2017).

The main advancement of our framework consists in operationalising the concept of provisioning systems (Brand Correa and Steinberger, 2017; Fanning et al., 2020; Lamb and Steinberger, 2017; O'Neill et al., 2018) by introducing the concept of 'provisioning factors'.



1. The bivariate cross-country relationship between energy use and need satisfaction follows a typical saturation curve. High need satisfaction is reached at moderate levels of energy use, beyond which further energy use does not improve need satisfaction.

2. For countries achieving high values of a beneficial provisioning factor, need satisfaction outcomes tend to be significantly better and less dependent on energy use. High need satisfaction is reached already at lower levels of energy use.

3. For countries exhibiting high values of a detrimental provisioning factor, need satisfaction outcomes tend to be significantly impaired and more dependent on energy use. High need satisfaction is reached only at higher levels of energy use.

Fig. 1. (A) Analytical framework for the provisioning of human need satisfaction. Building on the framework by O'Neill et al. (2018), our framework conceptualises provisioning factors as intermediaries that moderate the relationship between energy use and need satisfaction. (B) Qualitative depiction of our analysis. We assess how the relationship between energy use and need satisfaction (B.1) varies with different provisioning factors (B.2, B.3), and which provisioning factors are associated with socio-ecologically beneficial performance (higher achievements in, and lower energy requirements of, need satisfaction; B.2) or socio-ecologically detrimental performance (lower achievements in, and greater energy requirements of, need satisfaction; B.3).

Provisioning factors comprise all factors that *characterise* any element realising, or any aspect influencing, the provisioning of goods and services. This includes economic, political, institutional, infrastructural, geographic, technical, cultural and historical characteristics of provisioning systems (or the provisioning process), spanning the spheres of extraction, production, distribution, consumption and disposal. In other words, provisioning factors encompass all factors that affect how energy and resources are used to meet human needs (and other ends). For example, it matters whether provisioning caters to consumers with equal or unequal purchasing power, whether it occurs in an urban or rural context, in a growing or shrinking economy, whether electricity is available, and what transport infrastructure is in place. Provisioning factors are intermediaries that moderate the relationship between energy use and need satisfaction. Whereas provisioning systems are broad conceptual constructs that are difficult to measure, provisioning factors are tangible and measureable, and as such operational: provisioning factors *characterise* provisioning systems (or the provisioning process).

While interactions between energy use, provisioning factors and social outcomes may in principle go in all directions (Fanning et al., 2020; O'Neill et al., 2018), our focus here is on the role of provisioning factors for countries' *socio-ecological performance*, i.e. their achievements in, and energy requirements of, human need satisfaction (Fig. 1A). We use *regression-based moderation analysis* (Section 4.2) to assess how the relationship between energy use and need satisfaction varies with different provisioning factors, and subsequently model that relationship for different configurations of each provisioning factor (Fig. 1B). We further estimate how multiple provisioning factors jointly interact with the relationship between need satisfaction and energy use, using *multivariate regression analysis* (Section 4.3). While these are established statistical techniques, the way we apply them to our analytical framework and research questions is novel. Our approach allows us to coherently assess and compare the interactions of a broad range of provisioning factors, not just with need satisfaction or its ratio with energy use, but with the *relationship* between need satisfaction and energy use, across the international spectrum.

The variables assessed in our analytic framework (listed in Fig. 1A and detailed in Tables 1 and 2) capture key dimensions of human need, key categories of provisioning (state provision, political economy, physical infrastructure and geography) as well as *total final energy use*. Based on our understanding of human need theory (Doyal and Gough, 1991; Max-Neef, 1991) and provisioning systems (Brand Correa and Steinberger, 2017; Gough, 2019; O'Neill et al., 2018; Fanning et al., 2020), we analyse electricity access, democratic quality and income equality as provisioning factors (intermediaries) rather than as indicators of human need satisfaction (outcomes).

3. Data

3.1. Variables and data sources

We operationalise energy use in terms of total final energy use per capita, need satisfaction in terms of six key dimensions of human need (Table 1), and provisioning factors in terms of 12 diverse political, economic, geographic, and infrastructural factors (Table 2). Due to limited data availability, the assessed variables provide only a partial operationalisation of each of the three analytic domains, and are

Table 1
Human need satisfaction variables used in the analysis.

Variable name	Description and [units]	Sufficiency threshold	Indicator source
Healthy life expectancy	Average healthy life expectancy at birth [years]	65 years	IHME GBD
Sufficient nourishment	Percentage of population meeting dietary energy requirements [%], calculated as the reverse of *Prevalence of undernoursihment*, rescaled onto a scale from 0 to 100%	95%	WB WDI 2020
Drinking water access	Percentage of population with access to improved water source [%]	95%	WB WDI 2017
Safe sanitation access	Percentage of population with access to improved sanitation facilities [%]	95%	WB WDI 2017
Basic education	Education index [score]	score of 75	UNDP HDR
Minimum income	Absence of income shortfall below \$3.20/day [%], calculated as the reverse of the *Poverty gap at \$3.20 a day (2011 PPP)*	95%	WB WDI 2020

Saturation transformations are applied to all need satisfaction variables (see Supplementary Materials Section C.4.2). Indicator sources are: the Global Burden of Disease Study (IHME GBD; Institute for Health Metrics and Evaluation, 2017), the World Development Indicators (WB WDI; World Bank, 2017, 2020), and the Human Development Report 2013 (UNDP HDR; UNDP, 2013).

somewhat confined to variables reflecting a Western-industrial understanding of development (which have better data availability). Following O'Neill et al. (2018), we define a threshold value for 'sufficient' need satisfaction as a minimum societal goal for each assessed need (listed in Table 1 and discussed in Supplementary Materials Section C.1). Our energy data, sourced from the International Energy Agency (2015), provide a 'production-based' account of total final energy use, and hence do not account for the energy footprints of imported goods and services or international travel, due to poorer international coverage of consumption-based energy indicators. Data sources for our need satisfaction and provisioning factor variables are detailed in Tables 1 and 2, respectively.

3.2. Data sample

To ensure consistency and comparability, we use the same sample of countries throughout the analysis. Our sample, determined as the largest possible set of countries with data available for all selected variables, comprises 106 countries that together account for about 90% of the global population, 89% of global total final energy use, and 92% of global GDP. We perform a cross-sectional analysis, using 2012 as our basic year of analysis. However, we fill data gaps for 2012 in some cases by drawing on surrounding years for trade and transport infrastructure (2010–2014), income inequality (2009–2015), and minimum income (2009–2015; 2008 for Japan).

4. Methods

4.1. Bivariate relationship between need satisfaction and energy use

To assess the relationship between need satisfaction (NS) and energy use (ENU) across countries i, we perform bivariate linear ordinary least squares regressions, separately for each need satisfaction variable.

$$\widetilde{NS}_i = a + b\ \widetilde{ENU}_i + e_i \tag{1}$$

Table 2
Provisioning factor variables used in the analysis.

Variable name	Description and [units]	Transformation applied	Indicator source
Electricity access	Percentage of population with access to electricity [%]	Saturation	WB WDI 2017
Access to clean fuels	Percentage of population with access to non-solid fuels [%]	Saturation	WB WDI 2017
Trade & transport infrastructure	Quality of trade and transport-related infrastructure [score], component of the *Logistics performance index*	Identity	WB WDI 2017
Urban population	Percentage of population living in urban areas [%]	Identity	WB WDI 2017
Public service quality	Quality of public services, civil service, and policy implementation [score], calculated as *Government effectiveness,* rescaled onto a scale from 1 to 6	Identity	WB WGI
Public health coverage	Percentage of total health expenditure covered by government, non-governmental organisations, and social health insurance funds [%]	Identity	WB WDI 2017
Democratic quality	Ability to participate in selecting government, freedom of expression and association, free media [score], calculated as *Voice and accountability,* rescaled onto a scale from 1 to 6	Saturation	WB WGI
Income equality	Equality in household disposable income [score], calculated as the reverse of the *Gini index*	Saturation	SWIID
Economic growth	3-year (2010–2012) average percentage annual growth rate of GDP per capita in constant 2011 \$ PPP [%], calculated based on Gujarati, 1995, pp. 169–171	Identity	WB WDI 2017
Extractivism	Share of total value generation obtained from total natural resource rents [% of GDP]	Logarithmic	WB WDI 2017
Foreign direct investments	Share of foreign direct investments (net inflow) in total value generation [% of GDP]	Logarithmic	WB WDI 2017
Trade penetration	Share of total value generation that is traded [% of GDP], calculated as $\lvert Import\ value\rvert + \lvert Export\ value\rvert$	Identity	WB WDI 2020

Indicator sources are: the World Development Indicators (WB WDI; World Bank, 2017, 2020), the Worldwide Governance Indicators (WB WGI; World Bank, 2018; Kaufmann et al., 2011), and the Standardized World Income Inequality Database v6.2 (SWIID; Solt, 2020).

The regression estimates the coefficient b which describes the statistical association between energy use and need satisfaction. In this case, b can be interpreted as the marginal effect of energy use on need satisfaction (mathematically: $\partial\widetilde{NS}/\partial\widetilde{ENU}$), indicating the change in need satisfaction $\Delta\widetilde{NS}$ one would expect for a unit change in $\widetilde{ENU}$ (not necessarily a causal effect). In what follows, our use of the term 'marginal effect' should be interpreted in the above sense.

Throughout our analysis, all regressions are performed on transformed and standardised variables (denoted by a $\widetilde{tilde}$). For each variable, we determine a single 'best-suited' transformation (Supplementary Materials Section C.4) which we use consistently throughout our analysis. On that basis, we use logarithmic transformations for our energy use variable $(\widetilde{ENU}_i = \log(ENU_i))$, and saturation transformations (as in Steinberger and Roberts, 2010) for all need satisfaction variables $(\widetilde{NS}_i = \log(NS_{sat} - NS_i))$, with saturation asymptotes NS_{sat} detailed in Table C.1 in the Supplementary Materials.

4.2. Single provisioning factors as moderators of the relationship between need satisfaction and energy use

Based on our method to determine the best-suited variable transformations (Supplementary Materials Section C.4), we apply different types of transformations (identity, logarithmic, or saturation) to different provisioning factor variables (listed in Table 2).

To assess how the relationship between need satisfaction and energy use varies with different provisioning factors, we analyse each provisioning factor separately as a moderator of the relationship between energy use and a given need satisfaction variable. In this case, moderation can be statistically estimated based on a multivariate regression of need satisfaction on energy use, a provisioning factor (*PF*), and their interaction term (product), as joint predictors.

$$\widetilde{NS}_i = a + b_1\,\widetilde{ENU}_i + b_2\,\widetilde{PF}_i + b_3\,\widetilde{ENU}_i{}^{*}\widetilde{PF}_i + e_i \tag{2}$$

Due to the interaction term ($\widetilde{ENU}^{*}\widetilde{PF}$), the marginal effect of energy use on need satisfaction is, in this case, a function of the provisioning factor ($\partial\widetilde{NS}/\partial\widetilde{ENU} = b_1 + b_3\,\widetilde{PF}$), and the marginal effect of the provisioning factor on need satisfaction depends on the level of energy use ($\partial\widetilde{NS}/\partial\widetilde{PF} = b_2 + b_3\,\widetilde{ENU}$). This approach allows us to compare the relationship between energy use and need satisfaction (and its significance) for different values of each provisioning factor, and conversely, to assess the marginal effect of each provisioning factor (and its significance) for different levels of energy use.

As we are interested in the marginal effects of energy use and each provisioning factor, we adopt Brambor et al.'s (2006) approach to analyse the significances of the respective marginal effects of energy use ($\partial\widetilde{NS}/\partial\widetilde{ENU}$) and a given provisioning factor ($\partial\widetilde{NS}/\partial\widetilde{PF}$) rather than analysing the significances of the individual coefficients (b_1, b_2, b_3). We thus calculate the standard errors of the marginal effects and determine their significances based on their confidence intervals (Supplementary Materials Section C.2). We also use the confidence intervals to estimate the maximum and minimum levels of the provisioning factor at which the marginal effect of energy use on need satisfaction is significant ($\widetilde{PF}_{min^{**}}$, $\widetilde{PF}_{\max^{**}}$) as well as the energy use intervals over which the marginal effect of the provisioning factor is significant (Supplementary Materials Section C.3).

4.2.1. Modelled relationship between need satisfaction and energy use for alternative configurations of single provisioning factors

We apply the coefficients (b_1, b_2, b_3) obtained from the regressions (Eq. (2)) to model need satisfaction outcomes for observed energy use and different provisioning factor values (observed, mean, minimum significant, and maximum significant, with the latter exemplified in Equation (3)).

$$\widetilde{NS}_{pred,i}\left(\widetilde{PF}_{max^{**}}\right) = a + b_1\,\widetilde{ENU}_i + b_2\,\widetilde{PF}_{max^{**}} + b_3\,\widetilde{ENU}_i{}^{*}\widetilde{PF}_{max^{**}} \tag{3}$$

4.2.2. Overall statistical effects of single provisioning factors

Finally, to assess and compare the overall statistical effects and relevance of each provisioning factor, we pool the statistical effects of each provisioning factor across all need satisfaction variables and all observed energy use values for which the marginal effect of the provisioning factor is significant. For this purpose, we formulate the standardised statistical effect of a provisioning factor as the difference in predicted need satisfaction for the maximum vs. minimum significant values of the provisioning factor, expressed as a fraction of the respective empirical need satisfaction range.

$$\Delta NS_{pred,i}\left(\Delta\widetilde{PF}\right) = \frac{NS_{i,pred}\left(\widetilde{PF}_{max^{**}}\right) - NS_{i,pred}\left(\widetilde{PF}_{min^{**}}\right)}{NS_{max} - NS_{min}} \tag{4}$$

We consider this standardised statistical effect metric $\Delta NS_{pred,i}\left(\Delta\widetilde{\mathrm{PF}}\right)$ the most instructive and most comparable single measure of how the relationship between energy use and need satisfaction varies with a given provisioning factor, for a given level of energy use (which feeds into $NS_{i,pred}$). Pooling this metric across all need satisfaction variables provides a high-level indication of the dominant direction, strength, consistency and overall significance of the statistical effects of each provisioning factor. Acknowledging that the different dimensions of human need satisfaction are non-substitutable and incommensurable (Doyal and Gough, 1991), the pooled overall statistical effects metric should be taken primarily as a qualitative indication, not as an exact quantitative indication.

4.3. Joint statistical effects of multiple provisioning factors on the relationship between need satisfaction and energy use

To investigate how several provisioning factors jointly interact with the relationship between energy use and needs satisfaction, we perform a different set of multiple regressions of need satisfaction on energy use and three different provisioning factors as joint predictors (multiple provisioning factor regression).

$$\widetilde{NS}_i = \widehat{a} + \widehat{b}_1\,\widetilde{ENU}_i + \widehat{b}_2\,\widetilde{PF}_{1,i} + \widehat{b}_3\,\widetilde{PF}_{2,i} + \widehat{b}_4\,\widetilde{PF}_{3,i} + e_i \tag{5}$$

Due to our relatively small sample ($N = 106$), some level of correlation between the predictor variables, and the associated limits to precision and statistical power of regression estimates, we refrain from joint assessment of all provisioning factors and their interactions with energy use and each other. Our selection of the three provisioning factors used for this joint analysis is elaborated in Section 5.3.

4.3.1. Modelled relationship between need satisfaction and energy use for alternative configurations of multiple provisioning factors

To assess which joint configurations of key provisioning factors might be consistent with sufficient need satisfaction at low energy use, we model need satisfaction outcomes for stylised scenarios of 'median provisioning' and 'jointly beneficial provisioning' configurations (detailed in Section 5.3). We then apply the coefficients ($\widehat{b}_1$, $\widehat{b}_2$, $\widehat{b}_3$, $\widehat{b}_4$) obtained from the regressions (Eq. (5)) to model need satisfaction outcomes for alternative provisioning configurations *c*.

$$\widetilde{NS}_{pred,c,i} = \widehat{a} + \widehat{b}_1\,\widetilde{ENU}_i + \widehat{b}_2\,\widetilde{PF}_{1,c} + \widehat{b}_3\,\widetilde{PF}_{2,c} + \widehat{b}_4\,\widetilde{PF}_{3,c} \tag{6}$$

Finally, we estimate confidence intervals for the modelled need satisfaction outcomes based on delete-five jackknife resampling analysis (Friedl and Stampfer, 2006) with a resample size of 1000.

4.4. Testing validity and power of the regression models

For all regression models, we compute heteroscedasticity-robust standard errors (using the 'HC2′ method in the software package *R)*, check the normality of the residuals (Kolmogorov-Smirnov test, using $p > 0.05$), and assess multi-collinearity among the individual predictors based on Variance Inflation Factors (using $VIF > 5$ as a criterion for critical variance inflation). For the multiple provisioning factor models, we further perform a post-hoc analysis of the statistical power of the coefficients, using the WebPower package in *R* (Zhang and Yuan, 2018) and calculating effect sizes based on Cohen (1988). Details of these tests are given in Supplementary Materials Section C.5.

5. Results

5.1. The cross-country relationship between need satisfaction and energy use

Only 29 countries (28%) in our sample reach sufficient levels in all need satisfaction dimensions assessed here (health, nutrition, drinking water access, safe sanitation, education, minimum income). Each of these need-satisfying countries uses at least double, many even quadruple, the 27 GJ/cap deemed the maximum level of energy use that could be globally rendered sustainable (Grubler et al., 2018).

Our bivariate regression analysis confirms that while energy use is significantly correlated with need satisfaction, high levels of energy use seem neither necessary nor particularly beneficial for need satisfaction. Whereas at low levels of energy use, need satisfaction steeply increases with energy use, need satisfaction improvements with additional energy use quickly diminish at moderate levels of energy use and virtually vanish at high levels of energy use (Fig. 2). In other words, need satisfaction saturates with energy use. Based on the international trend (regressions), all assessed needs could be sufficiently met at 60 GJ/cap of final energy use. Beyond that level, additional energy use comes with little to no improvements in need satisfaction (Supplementary Materials Section A.1): a doubling in energy use is associated with less than a 5% increase in need satisfaction (10% for basic education). However, only 70% of the countries with energy use above 60 GJ/cap currently achieve sufficient need satisfaction (75% for 80 GJ/cap). Thus, high energy use alone is not sufficient to meet human needs. At low to moderate levels of energy use, there is a large spread in observed need satisfaction outcomes (vertical spread in Fig. 2), which cannot be explained by energy use alone.

5.2. *Variation of the relationship between need satisfaction and energy use with different configurations of single provisioning factors*

We find that need satisfaction outcomes are statistically better explained when a relevant provisioning factor is included as an intermediary that moderates the relationship between need satisfaction and energy use. Across multiple dimensions of human need, the relationship between need satisfaction and energy use varies significantly and systematically with the configuration of certain provisioning factors (Fig. 3). Without accounting for provisioning factors, the dependence of need satisfaction on energy use is generally overestimated.

Where the marginal effect of a provisioning factor is significant, both the level of need satisfaction associated with a particular level of energy use (vertical offsets in Fig. 3) and the extent to which need satisfaction outcomes depend on energy use (slopes in Fig. 3) vary with the value of the provisioning factor. Both of these aspects shape the energy requirements of sufficient need satisfaction.

Based on these associations, we distinguish three types of provisioning factors. *Beneficial provisioning factors* are associated with *socio-ecologically beneficial performance* (higher achievements in, and lower energy requirements of, human need satisfaction). Countries with high values of a beneficial provisioning factor tend to achieve higher levels of need satisfaction at a given level of energy use, and tend to reach a particular level of need satisfaction with lower levels of energy use, compared to countries with median values of the provisioning factor. *Detrimental provisioning factors* are associated with *socio-ecologically detrimental performance* (lower achievement in, and greater energy requirements of, human need satisfaction). Countries with high values of a detrimental provisioning factor tend to exhibit lower need satisfaction at a given level of energy use, and tend to reach a particular level of need satisfaction only at higher levels of energy use, compared to countries with median values of the provisioning factor. Lastly, *non-significant provisioning factors* do not show significant interactions with the relationship between energy use and need satisfaction.

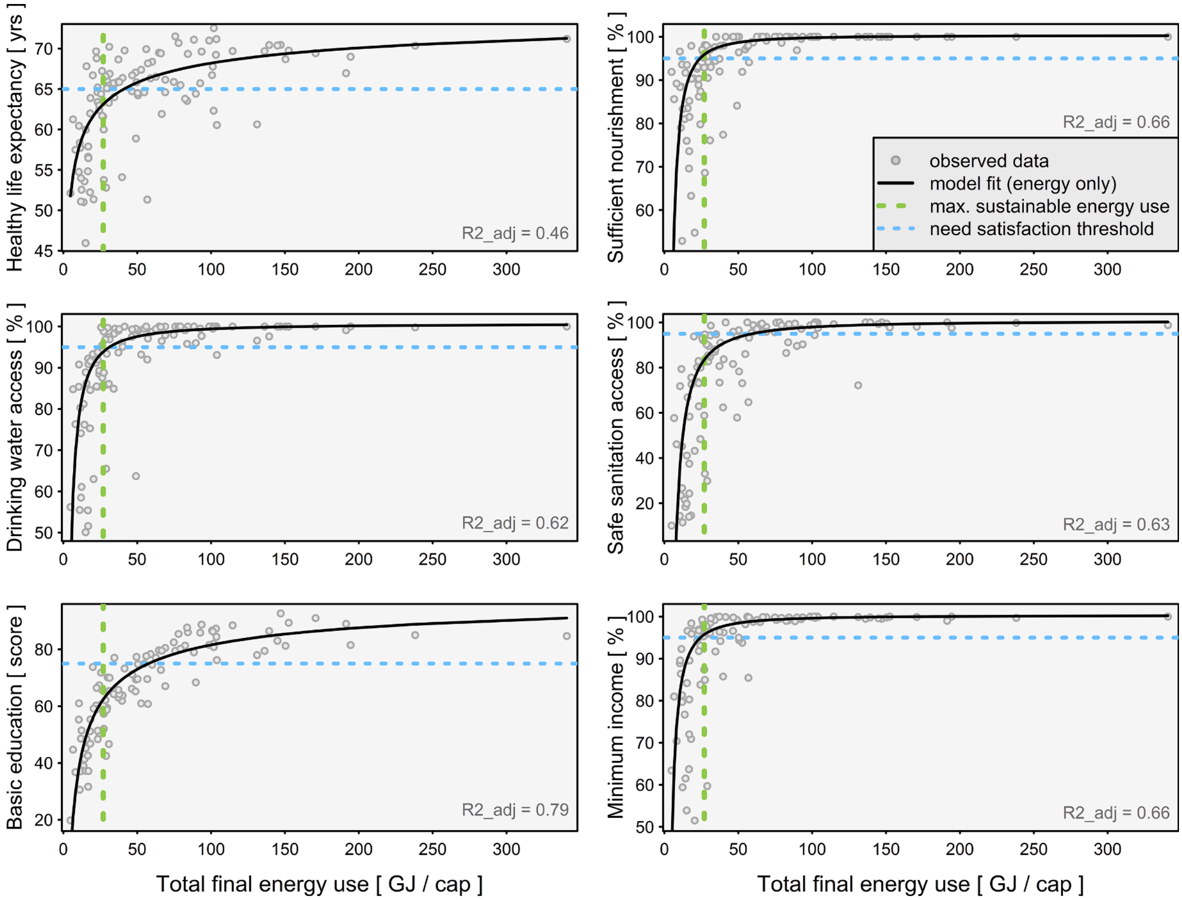


Fig. 2. Most human needs are currently not sufficiently met within sustainable levels of energy use. Cross-country relationships between different need satisfaction variables (*y*) and total final energy use (*x*) are shown as black lines, with data shown as grey dots. The green dashed line illustrates the 27 GJ/cap deemed the maximum level of energy use that can globally be rendered sustainable (Grubler et al., 2018). Thresholds for sufficient need satisfaction are shown by the dotted blue lines. *R2_adj* is the coefficient of determination, adjusted for the number of predictors.

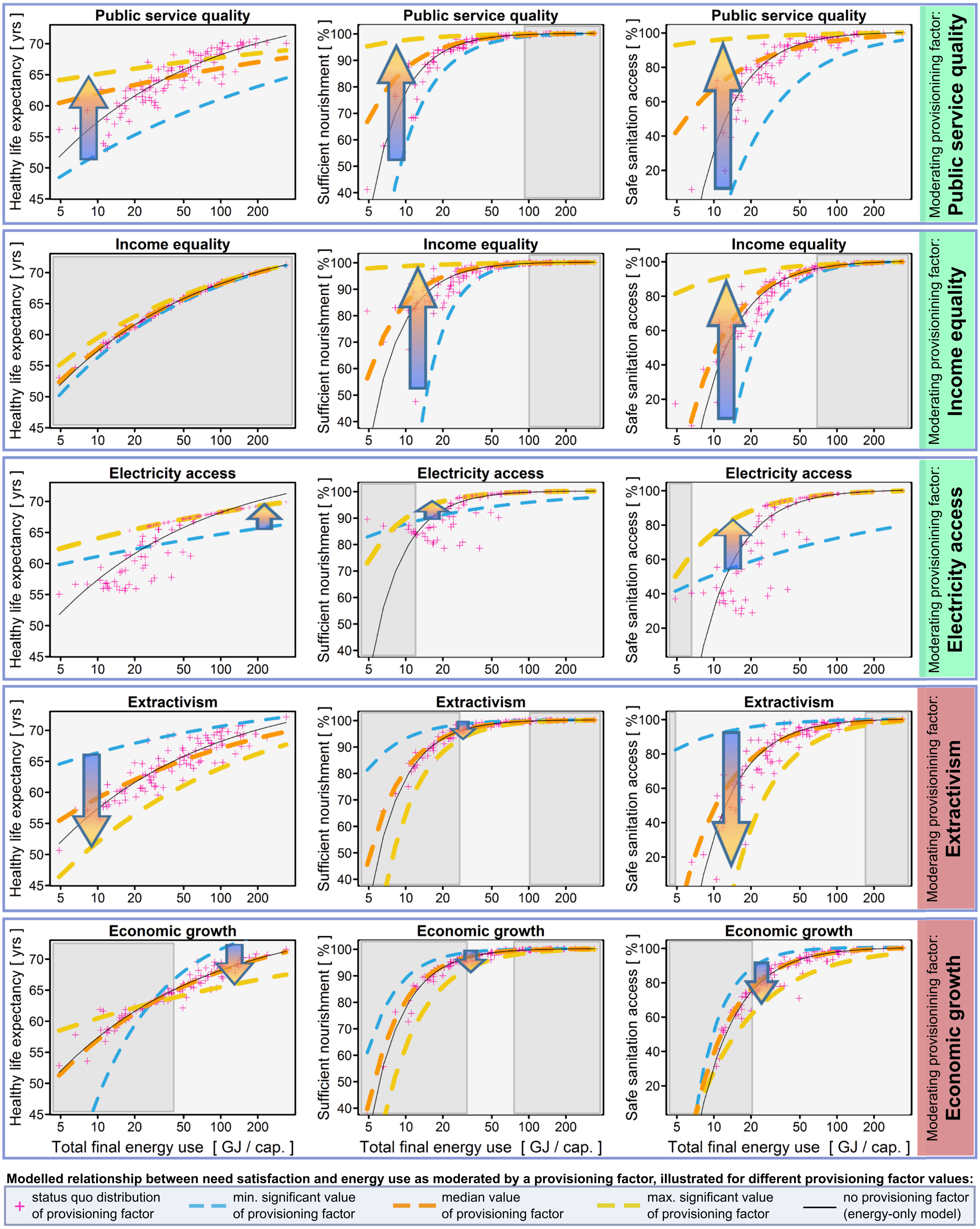


Fig. 3. The relationship between need satisfaction and energy use improves with beneficial provisioning factors (upward arrows) and deteriorates with detrimental provisioning factors (downward arrows). Each panel illustrates how the relationship between energy use (x) and a selected need satisfaction variable (y, columns) changes with different values (coloured dashed lines) of a selected provisioning factor (rows). Modelled need satisfaction outcomes are shown for maximum significant (yellow line), median (orange line), minimum significant (blue line) values and the status quo distribution (pink crosses) of each provisioning factor, and for the bivariate energy-only model without provisioning factor (black line). Energy use levels for which the marginal effect of a provisioning factor is not significant ($p > 0.05$) are shown by grey areas. All curves reflect saturation relationships (as shown in Fig. 2) but are shown here on a logarithmic x-axis.

Examples of how these interrelations manifest themselves in the relationship between energy use and need satisfaction are shown in Fig. 3. Public service quality, income equality, and electricity access can be identified as beneficial provisioning factors (upward arrows, green rows), whereas extractivism and economic growth can be identified as detrimental provisioning factors (downward arrows, red rows). Taking healthy life expectancy as a need satisfaction variable and public service quality as a provisioning factor (1st row, 1st column in Fig. 3), for example, we find life expectancy outcomes for high public service quality (yellow curve) to be significantly higher and less dependent on energy use than life expectancy outcomes for median (orange curve) or low public service quality (blue curve). Taking extractivism as a provisioning factor (4th row) instead, we find life expectancy outcomes for high levels of extractivism (yellow curve) are substantially lower and more dependent on energy use than they are for lower levels of extractivism (blue curve).

We find that the marginal effects of each provisioning factor are consistent in direction (beneficial or detrimental) across different need satisfaction variables, but vary substantially in magnitude and significance. For most need satisfaction variables, the marginal effects of a given provisioning factor also change with the level of energy use, with the strongest marginal effects prevailing at low energy use. Particularly strong marginal effects are found for public service quality, income equality, extractivism, and electricity access (for the latter, this is only partly visible in Fig. 3 because the difference between the minimum and maximum significant levels of electricity access is small). The marginal effect of economic growth is generally not significant at low levels of energy use, and the marginal effect of income equality is generally not significant at very high levels of energy use, as illustrated by the grey boxes in Fig. 3 and Fig. B.2 in the Supplementary Materials.

Both higher-than-average values of beneficial provisioning factors and lower-than-average values of detrimental provisioning factors are associated with socio-ecologically beneficial performance, and hence both constitute *beneficial provisioning configurations*. Conversely, both lower-than-average values of beneficial provisioning factors and higher-than-average values of detrimental provisioning factors are associated with socio-ecologically detrimental performance, and thus constitute *detrimental provisioning configurations*. The more beneficial a country's provisioning factor configuration is, the better its socio-ecological performance tends to be – and conversely, the more detrimental the former, the worse the latter. Indeed, the weakest observed need satisfaction outcomes are linked to detrimental configurations of key provisioning factors, in particular to insufficient access to electricity and clean fuels, poor trade and transport infrastructure, low public service quality, weak democracy, and the proliferation of extractivism (Fig. 3 and Supplementary Materials Fig. B.1–4). Our findings suggest that if such poorly performing countries had better configurations of these and other provisioning factors, their need satisfaction outcomes would likely be significantly better, even without higher energy use.

Finally, summarising all significant cases across all need satisfaction variables, we find that the statistical effects of each provisioning factor are highly consistent. Based on our analysis, each provisioning factor can be unambiguously categorised as either *consistently beneficial* (beneficial in some or all cases but never detrimental); *consistently detrimental* (detrimental in some or all cases but never beneficial); or *overall not significant* (predominantly not significant). Our analysis identifies public service quality, democratic quality, income equality, electricity access, access to clean fuels, trade and transport infrastructure, and public health coverage as consistently beneficial provisioning factors (Fig. 4). Extractivism and economic growth, on the other hand, are identified as consistently detrimental provisioning factors. Foreign direct investments and trade penetration are overall not significant.

5.3. Variation of the relationship between need satisfaction and energy use with joint configurations of multiple provisioning factors

To assess how the relationship between energy use and need satisfaction varies with joint configurations of multiple provisioning factors, we assess public service quality, income equality and extractivism jointly as predictors of need satisfaction, along with energy use. We select this particular set of provisioning factors for two reasons. First, they are theoretically very relevant. Public services and income equality have been suggested as important factors for sustainable welfare and a broad range of social outcomes (Bohnenberger, 2020; Büchs and Koch, 2017; Jorgenson, 2015; Wilkinson and Pickett, 2010). Extractivism has been identified as a key impediment to human development and human well-being in the context of environmental conflict (Martinez-Alier and Walter, 2016) and the 'resource curse' (Enriquez et al., 2019). Moreover, extractivism constitutes a major form of economic rent extraction which has been identified as a major threat to sustainable need satisfaction (Stratford, 2020; Stratford and O'Neill, 2020) through what Fanning et al. (2020) call 'appropriating systems'. Second, these provisioning factors all show significant interactions with the relationship between energy use and need satisfaction, while differing in the directions and strengths of their statistical effects (Figs. 3, 4 and B.2, B.5 in the Supplementary Materials).

Our joint analysis of these three provisioning factors underlines that each of them is significant for multiple and different human needs (Table 3). Conversely, for each need satisfaction variable, at least one of the three provisioning factors is significant. The marginal effects of these provisioning factors analysed jointly are overall consistent with their marginal effects found in the single provisioning factor moderation analysis, with slightly smaller magnitudes (as expected for a joint analysis) but importantly, consistent directions for all significant coefficients ($p < 0.05$). In other words, the statistical effects of these provisioning factors qualitatively hold in the context of multiple provisioning factors.

Our results suggest that countries that simultaneously possess high public service quality, high levels of income equality, and low levels of extractivism are likely to achieve a socio-ecologically beneficial performance across all assessed needs. To compare the relationship between need satisfaction and energy use for different joint configurations of these provisioning factors, we model need satisfaction outcomes for observed energy use values and three stylised joint provisioning factor configurations: 'status quo provisioning' (using each country's currently observed provisioning factor values); 'median provisioning' (using the international median of each provisioning factor for all countries); and 'jointly beneficial provisioning' (using the 90th percentile values of public service quality and income equality, and the 10th percentile value of extractivism, for all countries). We find that modelled need satisfaction outcomes for the jointly beneficial provisioning configuration are much better than outcomes modelled for a median provisioning configuration, and for most countries also much better than outcomes predicted for their status-quo provisioning configurations (Fig. 5).

The differences in modelled need satisfaction are particularly stark for countries with low energy use, where need satisfaction outcomes modelled for a median provisioning configuration are already substantially better than outcomes modelled for their status-quo provisioning configuration. For countries with high energy use, it is the other way around. These results reflect that countries with high energy use tend to have overall beneficial provisioning configurations, whereas countries with low energy use tend to have overall detrimental ones. While beneficial provisioning configurations thus show some level of correlation with energy use, there is no critical multi-collinearity ($VIF < 5$), implying that marginal effects can still be reasonably estimated. Indeed, all significant coefficients ($p < 0.05$) display high statistical powers

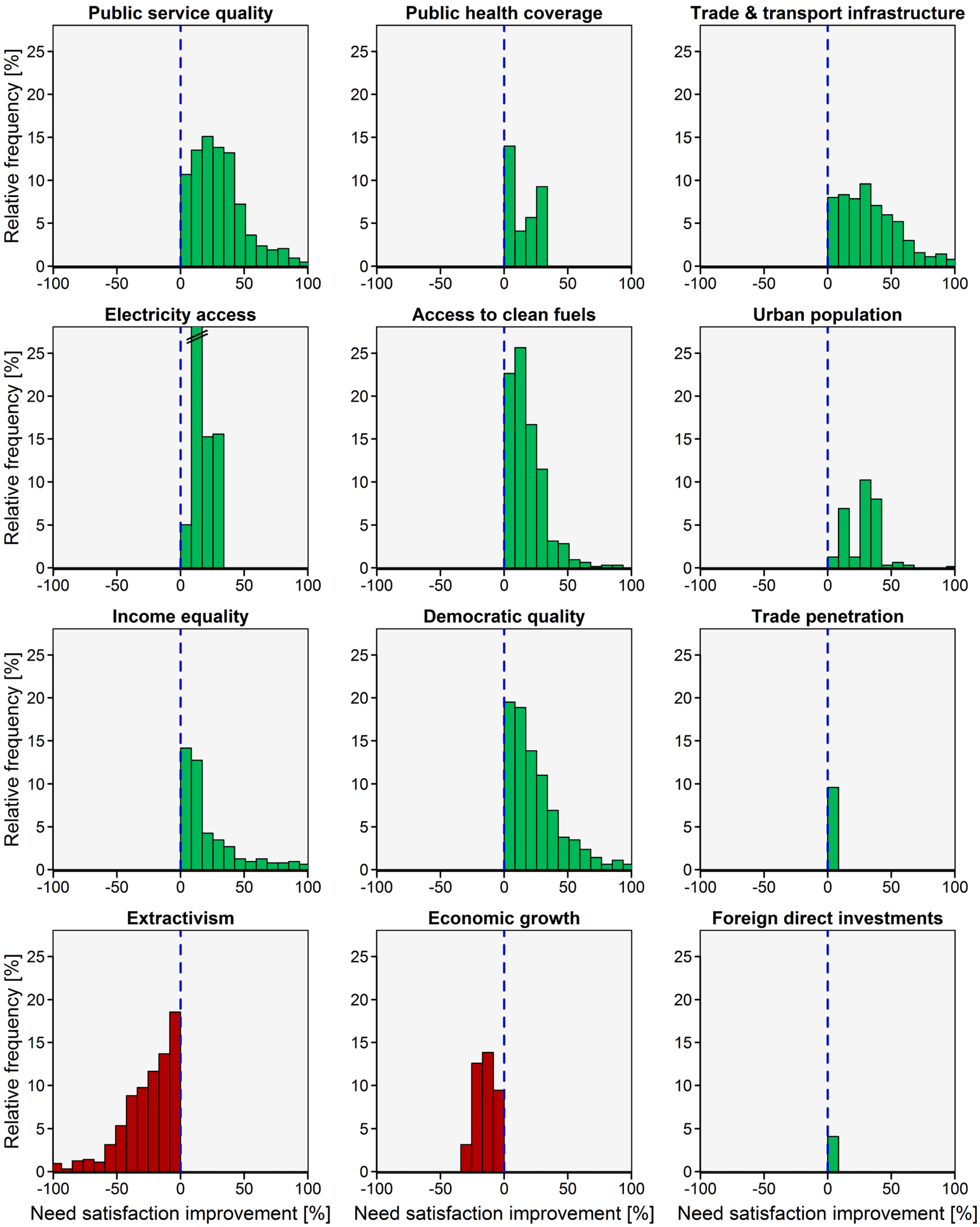


Fig. 4. Most assessed provisioning factors are consistently associated with either beneficial (green) or detrimental (red) socio-ecological performance. For each provisioning factor (titles), the relative frequency (*y*) of cases for which higher values of the provisioning factor are associated with different degrees of need satisfaction improvement (*x*) is shown, based on model outcomes pooled across all need satisfaction variables. 'Need satisfaction improvement' is the difference between modelled need satisfaction for the maximum significant value of each provisioning factor and modelled need satisfaction for the corresponding minimum significant value, expressed as a percentage of the range of the need satisfaction variable. The disaggregated data underlying these histograms are shown in Supplementary Materials Figure B.5. The ranges on the x- and y-axes are chosen for best illustration on a common axis, with a small number of data points (~2%) falling outside of the x-range, and one value falling outside of the y-range (the relative frequency of the second bin of electricity access is 59%).

Table 3
Need satisfaction improves with public service quality and income equality but deteriorates with extractivism.

	Healthy life expectancy	Sufficient nourishment	Drinking water access	Safe sanitation access	Basic education	Minimum income
Total final energy use	0.31***	0.54***	0.43***	0.41***	0.60***	0.64***
Public services	0.34***	0.13	0.24**	0.27**	0.30***	−0.02
Income equality	−0.04	0.23**	0.07	0.13*	0.09	0.20**
Extractivism	−0.30***	−0.10	−0.29***	−0.22**	−0.03	−0.19**
R^2_{adj}	0.62	0.72	0.76	0.75	0.83	0.71

Results from multiple provisioning factor models each regressing a different need satisfaction variable (columns) on the same four predictor variables (rows). The coefficients are directly comparable (in terms of standardised international variability), with positive coefficients indicating a positive association with need satisfaction. Significance levels are: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, using heteroscedasticity-robust p-values. Coefficients with statistical powers > 0.8 are underlined. R^2_{adj} is the coefficient of determination, adjusted for the number of predictors.

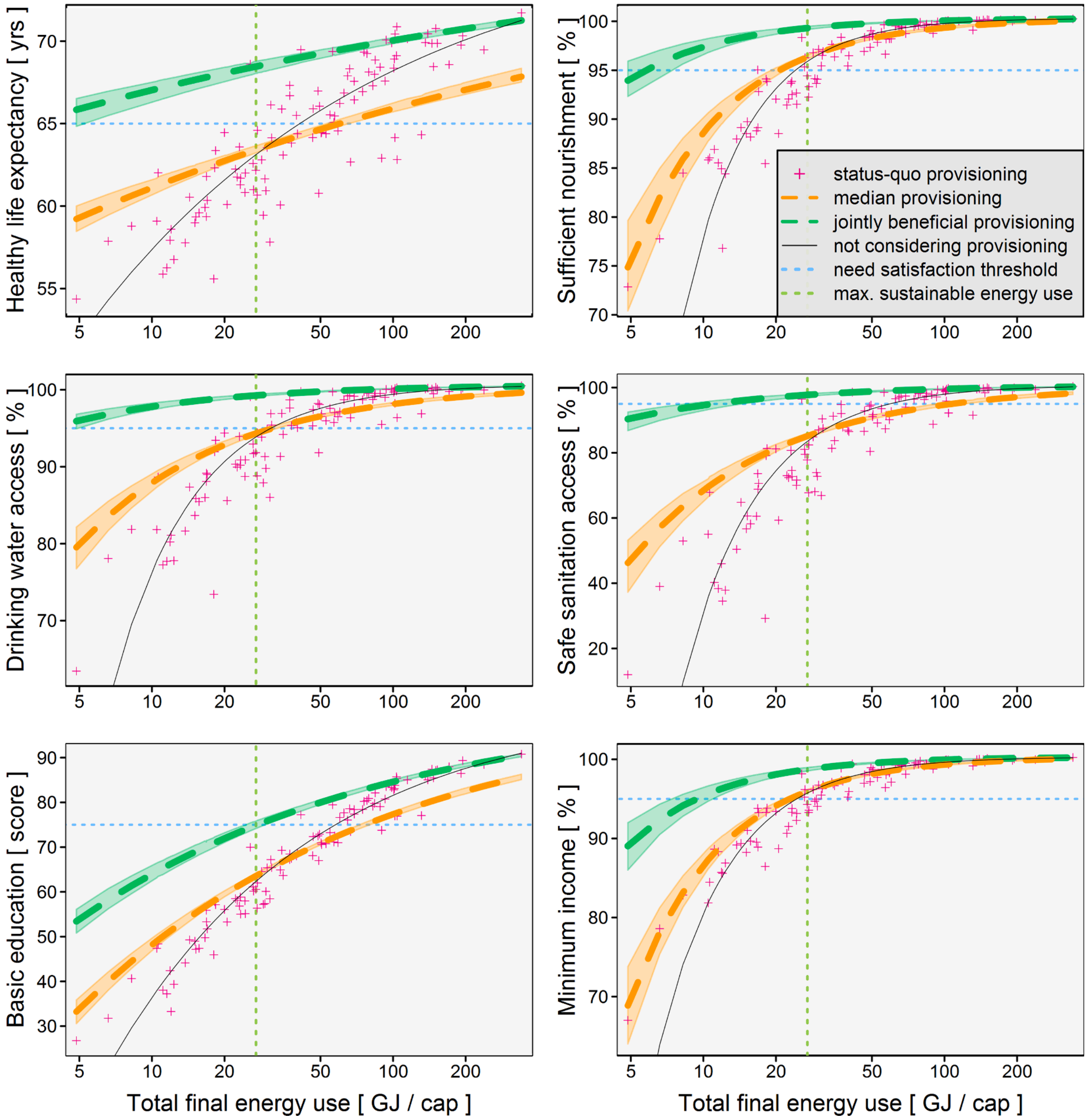


Fig. 5. With a 'jointly beneficial provisioning' configuration (high public service quality, high income equality and low extractivism), all human needs assessed in this study could likely be sufficiently satisfied within sustainable levels of energy use. Modelled need satisfaction outcomes (*y*) are shown for observed energy use (*x*) and three provisioning factors (public service quality, income equality, extractivism) in alternative joint configurations (detailed in text): 'jointly beneficial provisioning' (green dashed line), 'median provisioning' (orange dashed line; using international median provisioning factor values for all countries), and 'status-quo provisioning' (pink crosses; using each country's current provisioning factor values). 95% confidence intervals are shown as shaded green and orange areas. The vertical green dotted lines indicate the maximum level of energy use deemed sustainable (~27 GJ/cap). The horizontal blue dotted lines represent the respective thresholds for sufficient need satisfaction.

($1 - \beta > 0.8$), with one exception (the coefficient for income equality on safe sanitation access). The correlations of each provisioning factor with energy use are accounted for in the single provisioning factor moderation analysis.

Our models reproduce our empirical finding that no country with levels of energy use deemed sustainable (<27 GJ/cap) sufficiently satisfies all needs (most do not sufficiently satisfy any need), based on their status-quo provisioning configurations (pink crosses in Fig. 5). For a median provisioning configuration (orange curves), modelled need satisfaction outcomes at or below sustainable levels of energy use remain well below the sufficiency threshold for several needs. By contrast, for a jointly beneficial provisioning configuration (green curves), modelled outcomes for all need satisfaction variables reach the respective sufficiency thresholds within sustainable levels of energy use. While the levels of energy use associated with sufficient need satisfaction for the jointly beneficial provisioning configuration may seem fairly low (from < 5 GJ/cap to ~ 27 GJ/cap), they are broadly in line with bottom-up estimates of the energy requirements of sufficient need satisfaction (Rao et al., 2019; Millward-Hopkins et al., 2020). In summary, our model results suggest that for beneficial configurations of key provisioning factors, the energy requirements of need satisfaction are significantly reduced, such that high levels of need satisfaction could in principle be achieved within sustainable levels of energy use.

6. Discussion

Our findings suggest that the satisfaction of fundamental human needs does not only depend on energy use, but also on a broad range of provisioning factors that act as intermediaries between need satisfaction and energy use. Need satisfaction outcomes and their energy requirements vary substantially with the configuration of key provisioning factors. Accounting for provisioning factors allows us to statistically explain a significant share of international need satisfaction outcomes and their relation to energy use, whereas not accounting for provisioning factors generally leads to overestimating the importance of energy use. We thus find that human need satisfaction is generally less dependent on energy use than previous empirical studies have suggested. At the same time, high energy use alone is not sufficient to meet human needs. Both the social outcomes and the ecological sustainability of human development pathways are tightly linked to the configurations of key provisioning factors. A focus on provisioning factors may hence be crucial for achieving the twin goals of meeting everyone's needs and remaining within planetary boundaries – goals which sit at the heart of the Sustainable Development Goals, but which are incompatible with current development pathways (Gough, 2017; O'Neill et al., 2018; Raworth, 2017).

6.1. *The significance of provisioning configurations for socio-ecological performance*

The associations we find between provisioning factor configurations and socio-ecological performance suggest what level of need satisfaction a country is likely to reach at a given level energy use, and at what level of energy use it could likely achieve a particular level of need satisfaction, depending on its provisioning configuration. Countries with beneficial provisioning configurations are likely to achieve higher need satisfaction at a given level of energy use, and could likely reach a particular level of need satisfaction with less energy use, compared to the international trend. The better a country's provisioning configuration is, the better its socio-ecological performance tends to be. While not making any causal claims, our analysis suggests that changes in the configurations of key provisioning factors are likely to be accompanied by changes in socio-ecological performance broadly in line with the statistical associations presented here (so long as these associations themselves do not significantly change over time). Improvements in provisioning configurations would likely have socio-ecologically beneficial consequences. Thus, the associations we find between provisioning factor configurations and socio-ecological performance may suggest promising new policy strategies for countries to pursue in order to reconcile ecological sustainability and human well-being.

For most provisioning factors, our results provide a clear case as to what kind of configuration is likely amenable to socio-ecologically beneficial performance: all but two provisioning factors are identified as either consistently beneficial or consistently detrimental. The marginal effects found for each provisioning factor individually maintain their directions and tend to maintain their significances in the context of multiple provisioning factors, while the marginal effects of different provisioning factors tend to complement each other, based on the explored cases (Figures 3, 4, B.2, B.3 and Tables 3, B.1, B.2). While scope and computational limitations preclude analysis of all possible provisioning factor combinations, the assessed cases suggest that a greater number of beneficially configured provisioning factors is associated with a greater likelihood of socio-ecologically beneficial performance.

6.2. *The potential and importance of low-energy need satisfaction*

Our model results suggest that for many countries where needs are currently not met, reaching sufficient need satisfaction without improvements in provisioning configurations would require very large increases in energy use. Much of this additional energy use could potentially be avoided if these countries significantly improved key provisioning factors in pursuit of sufficient need satisfaction. By contrast, many countries that currently achieve sufficient need satisfaction already exhibit fairly beneficial provisioning configurations, and could thus likely pursue substantial reductions in energy use without compromising sufficient need satisfaction – in particular if they further improved their provisioning configurations. Countries reaching highly beneficial configurations of multiple provisioning factors could potentially achieve sufficient need satisfaction within sustainable levels of energy use. These findings are consistent with bottom-up model estimates suggesting that all countries could in principle provide the material requirements of sufficient need satisfaction at low levels of energy use (13–18 GJ/cap), in a scenario of equitable, sufficient, technically efficient and largely collective provisioning (Millward-Hopkins et al., 2020). Furthermore, our assessment for currently deprived countries is corroborated by a household-level analysis for Nepal, Vietnam and Zambia, which suggests that basic need satisfaction does not necessarily require increased energy use but could be achieved through improved collective provisioning (Baltruszewicz et al., 2021).

Reducing energy use in affluent countries – without compromising sufficient need satisfaction – is crucial for both climate and social justice. Globally, large reductions in energy use are required to limit global warming to 1.5 °C without relying on negative emissions technologies (Grubler et al., 2018; IPCC, 2018; Haberl et al., 2020). Considerations of equity, capability and historical responsibility suggest that affluent countries should carry more than their pro-rata share of the global climate mitigation challenge (Anderson et al., 2020; Holz et al., 2018; Jackson, 2019; van den Berg et al., 2019). While a large share of the energy footprints of affluent countries appears to be unnecessary for need satisfaction (see also Chitnis et al., 2014; Druckman and Jackson, 2010; Oswald et al., 2020), they use up a substantial share of the dwindling global carbon budget which would be required for others to meet their basic needs (Gough, 2015, 2017; Lamb and Rao, 2015). So long as fossil fuels have a high share in the total energy mix, energy use above sustainable levels thus exacerbates climate and social injustice. Reducing energy use is also key for facilitating a faster decarbonisation of the energy system, and also seems desirable from the perspective of energy security and energy sovereignty (in particular for the transition to renewable energy).

6.3. Obstacles to low-energy need satisfaction?

In contemporary economies, reasonably beneficial provisioning configurations are found, if anywhere, only in countries with high energy use. This observation is neither surprising nor inconsistent with our analysis: while our findings suggest that countries with beneficial provisioning configurations likely *could* sufficiently meet human needs at relatively low energy use, this does not mean they would necessarily limit themselves to low energy use. Excess energy use is at least in part driven by factors other than need satisfaction, such as lock-in and escalation of energy-intensive needs satisfiers and provisioning modes (Brand Correa et al., 2020), luxury consumption and inequality in consumption levels (Oswald et al., 2020), planned obsolescence (Guiltinan, 2009), overproduction and overconsumption (Pirgmaier, 2020), profit making (Hinton, 2020), and expansion of production to keep up with financial pressures from debt and rent extraction (Hickel, 2020; Stratford, 2020; Stratford and O'Neill, 2020). Reducing the energy requirements of need satisfaction is a crucial step for reducing energy use, but getting affluent countries back within sustainable levels of energy use additionally requires tackling these and other drivers of excess energy use.

While the 'jointly beneficial provisioning' configuration we explore (high public service quality, high income equality and low extractivism) may seem fairly ambitious, it is neither implausible nor out of reach: Belgium already meets (and surpasses) these conditions, while Austria, Germany, Switzerland, Iceland, and Malta all come close. Furthermore, we find that high public service quality, high income equality, and low extractivism are all correlated (Pearson's r of 0.49 for public service quality and income equality, −0.61 for public service quality and extractivism, and −0.38 for income equality and extractivism). In other words, they tend to go together — a tendency that could lend itself particularly well for potential policy packages.

In countries with low energy use, provisioning configurations are generally far from beneficial. However, we argue there is nothing inherent in beneficial provisioning configurations that would require high levels of energy use or categorically prevent rapid improvements. Detailed bottom-up analysis for Brazil, India and South Africa suggests rather low energy requirements (<5 GJ/cap) for rollout of the infrastructure and physical capital required to provide sufficient need satisfaction (Rao et al., 2019). Similarly low energy requirements for infrastructure rollout have been suggested for countries across the international spectrum (Millward-Hopkins et al., 2020). Operating a strong democracy does not inherently require high energy use, as cases like Costa Rica and Uruguay suggest (Lamb, 2016a, 2016b; Lehoucq, 2010). Greater income equality would not substantially increase energy use (Oswald et al., 2021). Moving away from extractivism and scaling back extractive industries would likely *reduce* energy use (Krausmann et al., 2018).

6.4. Paradigmatic provisioning factors: Economic growth and (in)equality

Our findings challenge the influential claim that economic growth is beneficial to human well-being. In fact, our results suggest that at moderate or high levels of energy use, economic growth is associated with socio-ecologically detrimental performance (lower achievements in, and greater energy requirements of, need satisfaction). Given the close coupling between economic activity and energy use (Steinberger et al., 2020), these findings imply that economic growth beyond moderate levels of affluence is socio-ecologically detrimental. At low levels of energy use (currently corresponding to low levels of affluence), economic growth exhibits no significant association with need satisfaction. Joint analysis with other provisioning factors corroborates the adverse outcomes associated with economic growth (Supplementary materials Table B.2). These findings run contrary to the near-universal policy goal of fostering economic growth. Due to our novel approach of analysing economic growth as a provisioning factor, our results analytically integrate multiple critiques of growth: the social limits and detriments of growth (Hirsch, 1976; Kallis, 2019; Mishan and Mishan, 1967; O'Neill, 2015); the ecological unsustainability of growth (Dietz and O'Neill, 2013; Jackson, 2017; Kallis, 2018, 2019); and the incompatibility of growth with limiting global warming to 1.5 °C (Antonakakis et al., 2017; D'Alessandro et al., 2020; Haberl et al., 2020; Hickel and Kallis, 2020). Abandoning the pursuit of economic growth beyond moderate levels of affluence thus appears ecologically necessary and socially desirable. Rendering a non-growing economy socially sustainable will require a fundamental political-economic transformation to remove structural and institutional growth dependencies (Hickel, 2020; Hinton, 2020; Kallis et al., 2020; Parrique, 2019; Stratford, 2020; Stratford and O'Neill, 2020).

Our findings also add new perspectives to the controversial debate on how income (in)equality relates to energy use and carbon emissions (Grunewald et al., 2017; Jorgenson et al., 2016; Oswald et al., 2021; Rao and Min, 2018b). By assessing income equality as a provisioning factor, our analysis integrates previous findings related to both biophysical resource use and social outcomes. The positive association we find between income equality and socio-ecological performance supports claims that improving income equality is compatible with rapid climate mitigation (D'Alessandro et al., 2020; Oswald et al., 2021; Rao and Min, 2018b), beneficial for social outcomes (Wilkinson and Pickett, 2010) and favourable (Jorgenson, 2015; Knight and Rosa, 2011; Oswald et al., 2021) or even required (Gough, 2017) for reconciling human well-being with ecological sustainability. These findings are particularly important as inequality is on the rise in many countries (Piketty and Saez, 2014), and as efforts to limit resource use could lead to escalating inequality through intensified economic rent extraction (Stratford, 2020). Taken together, these analyses provide a strong case for redistributive policies that establish both minimum and maximum income and/or consumption levels (Alexander, 2014; Fuchs and Di Giulio, 2016; Gough, 2020).

6.5. Implications for the broader political-economic regime and specific policy proposals

Given that *no* country is even close to achieving sufficient need satisfaction within sustainable levels of energy use, the inadequacy of provisioning systems is not a country-specific issue, but ultimately a systemic issue. It appears to be an issue of the economic system and the overarching political-economic regime *per se*. The political-economic regime fundamentally shapes how societies organise their economies and their provisioning systems, and hence their propensities to pursue and abilities to reach beneficial provisioning factor configurations. Ultimately, the socio-ecological performance of countries is thus highly contingent upon the broader political-economic regime. In the empirical reality of the dominant political-economic regime, detrimental provisioning factors like economic growth and extractivism are actively pursued, whereas beneficial factors like income equality, public services and democracy are often sidelined or undermined (Chomsky and Barsamian, 2017). Our findings may thus imply that the dominant political-economic regime is unsuitable for meeting the needs of all people at sustainable levels of energy use (as argued by Gough, 2017). Hence, changes in provisioning systems may need to be embedded in a more fundamental transformation of the political-economic regime that would repurpose and reorganise the economy to prioritise providing sufficient need satisfaction within sustainable levels of energy use. Potential pillars of such a transformation have been elaborated in recent literature on Doughnut-economics (Stratford and O'Neill, 2020), sustainable welfare (Gough, 2017) and Degrowth (Chertkovskaya et al., 2019; Hickel, 2020; Kallis et al., 2020; Liegey and Nelson, 2020; Parrique, 2019).

A range of policy proposals map onto our analysis of what changes in provisioning would likely be suitable for sufficient need satisfaction at low energy use. An important proposal is the idea of providing Universal Basic Services (Coote and Percy, 2020), including universal access to electricity and clean fuels (Gough, 2019). Proposals of minimum and maximum income thresholds as well as higher taxes on wealth and inheritance could also establish greater equality of purchasing power (Alexander, 2014; Parrique, 2019). Modal shifts in need satisfiers (e.g. from an animal-based to a plant-based diet, from space heating to insulation) and their provision (e.g. from individual to collective transport, from motorised to active travel) could provide the same level of need satisfaction with much lower energy use (Brand Correa et al., 2020; Creutzig et al., 2018). Sortition-based citizens' assemblies with implementation powers could strengthen democracy by re-rooting it in inclusive deliberation, insulated from vested interests (Smith, 2009). More broadly, the way societies understand and measure progress and development should move away from the primacy of GDP and economic growth to prioritising equitable human well-being and ecological sustainability (Dietz and O'Neill, 2013; Raworth, 2017; Gough, 2017).

6.6. *Limitations and future research*

A number of limitations apply to our analysis. First, as no country achieves sufficient need satisfaction at low energy use, we explore configurations with no direct empirical precedent. Second, our analysis is one of statistical association and moderation, and neither makes causal claims nor relies on causal assumptions. Third, while our analysis allows us to estimate at what level of energy use a particular level of need satisfaction could likely be reached for a given provisioning configuration, it does not allow us to estimate likely levels of energy use *per se*. Fourth, while we analyse how the relationship between need satisfaction and energy use varies with the configurations of provisioning factors, these associations could potentially change over time. Fifth, by necessity (data availability, scope, statistical and computational limits), we explore only a limited variety of conceivable provisioning factors, possible combinations and potential interactions between them. While we analyse two kinds of international interactions as provisioning factors (trade penetration and foreign direct investments), other potentially relevant international interactions such as unequal exchange, transnational corporations, or debt and aid flows are not included in our analysis, highlighting an important topic for further exploration. Future research could also pursue longitudinal and dynamic analyses of the associations under consideration (see also Steinberger et al., 2020), account for energy embodied in imports and exports, and explore broader sets of both need satisfaction variables and provisioning factors, including measures related to power, commons, and material stocks such as infrastructure, machinery and buildings (Fanning et al., 2020). Sixth, we cannot rule out the possibility that our variables act to some extent as proxies for other correlated variables (although this would not change our high-level results). Finally, the findings of our cross-national study are of a general nature: while they have important general implications, implementations for specific countries need to be context-sensitive.

7. Conclusions

This study set out to address a crucial yet unstudied issue at the heart of the challenge to meet the needs of all people while remaining within planetary boundaries: how does the relationship between energy use and need satisfaction vary with different provisioning factors, and what configurations of these factors are suitable for sufficient need satisfaction within sustainable levels of energy use?

Our analysis suggests that the way countries operate their economies in the current political-economic regime is fundamentally misaligned with the twin goals of meeting human needs and ensuring ecological sustainability: in 77 of the 106 countries we analysed, people are significantly deprived of fundamental human needs, whereas the 29 countries in which these needs are sufficiently met all feature highly unsustainable levels of energy use. Based on a novel analytical framework and approach, we find that differences in the relationship between energy use and need satisfaction are linked to the configurations of a wide range of provisioning factors. For beneficial configurations of provisioning factors, need satisfaction outcomes tend to be significantly better, and substantially less dependent on energy use. For detrimental configurations of provisioning factors, it is the other way around: need satisfaction outcomes are significantly impaired and associated with higher levels of energy use.

Our analysis suggests that countries with beneficial configurations of key provisioning factors are more likely to reach high levels of need satisfaction at low levels of energy use. Countries with highly beneficial configurations of several key provisioning factors could potentially achieve sufficient need satisfaction within sustainable levels of energy use. Improvements in relevant provisioning factors may thus be crucial for ending human deprivation in currently underproviding countries without exacerbating ecological crises, and for tackling the ecological overshoot of currently needs-satisfying countries without compromising sufficient need satisfaction.

On that basis, we suggest that countries should pursue the provisioning configurations that our analysis identifies as beneficial, in particular, providing high-quality public services, strengthening democracy, establishing greater income equality, ensuring universal access to electricity and clean fuels, improving trade and transport infrastructure, increasing public health coverage, minimising extractive industries and abandoning economic growth beyond moderate levels of affluence. Given the dependence of provisioning systems on the broader political-economic regime, and the tight coupling between energy use and economic growth (a central pillar of the dominant regime), a fundamental transformation of the political-economic regime may be necessary to prioritise and realise the provisioning of sufficient need satisfaction within sustainable levels of energy use.

Our findings have important implications for development discourses, climate mitigation, and poverty eradication. They are particularly relevant for efforts to achieve the Sustainable Development Goals, Green New Deal programmes, 'Doughnut economics', and initiatives to 'build back better' after the Covid-19 crisis. Our analysis provides empirical support for transformative policies including Universal Basic Services, a minimum and maximum income, citizens' assemblies, and for moving away from the pursuit of economic growth and extractivism towards a prioritisation of human needs and ecological sustainability.

Overall, this study offers and informs a new way of understanding the link between human development (in terms of need satisfaction) and ecological sustainability (in terms of energy use), and the role of the economy and key provisioning factors in reconciling these twin goals. Further research is needed to better understand the mechanisms underpinning the role of provisioning factors, to inform the design of policies to act on them, and to guide the design of and transition to an economic system that is aligned with human needs, equity and ecological sustainability.

CRediT authorship contribution statement

Jefim Vogel: Conceptualization, Methodology, Data curation, Investigation, Formal analysis, Software, Visualization, Writing - original draft, Writing - review & editing. **Julia K. Steinberger:** Conceptualization, Methodology, Supervision, Writing - review & editing. **Daniel W. O'Neill:** Conceptualization, Methodology, Supervision, Writing - review & editing. **William F. Lamb:** Conceptualization, Methodology, Data curation, Software, Visualization, Supervision, Writing - review & editing. **Jaya Krishnakumar:** Methodology, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary materials

Supplementary materials to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2021.102287.

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