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Pietro Guarato

Carbon Capture, Utilization and Storage in Switzerland.

Volume 2 – The Institutional and Legal Framework

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MELiSSA

MICRO-ECOLOGICAL
LIFE SUPPORT SYSTEM
ALTERNATIVE

SUMMARY

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FORWARD

While volume 1 aimed at reviewing the fundamental scientific and technical aspects of CCUS which are necessary for policymakers to understand the manner CCUS processes work, volume 2 focuses on the analysis of policy and regulatory aspects connected with CCUS development, i.e. the institutional and legal conditions that regulate the capture, storage and use of carbon dioxide.

In this volume, we start by identifying the opportunities to regulate and encourage the large-scale deployment of CCUS in Switzerland which can be found in the existing legal provisions (related to different public policies such as climate policy, energy policy, environmental policy, etc.). The introduction of CCU, in particular, would represent a major conceptual shift in the legal status of CO_2, which would become a resource in this new context. Such a change leads us to investigate whether the existing provisions, in the current state of their formulation and implementation, are sufficient to regulate these new activities and uses of CO_2 in a coherent way or if, conversely, it is necessary to integrate and modify these provisions opportunely. In order to conduct such an investigation, we use the conceptual instrument of the Institutional Resource Regime, or IRR. The IRR is a theoretical framework which allows to analyze strengths and weaknesses of the regulations in force governing the use of a natural resource by considering at the same time the main elements of public policies related to the protection and/or exploitation of the resource and the specific arrangement of property and use rights of goods and services provided by this resource (Gerber 2006). Thus, the IRR investigates simultaneously public policies (PPs) and actual property rights (PRs) at work concerning the use of a natural resource, overcoming the limits of sector-based conceptual analysis which do not often recognize the importance of the interplay existing between these two dimensions of PPs and PRs.

We use the instrument of IRR in a prospective and analytical approach, to identify in a relatively straightforward manner the possible gaps and flaws of the current legislation, both in the PPs and in the PRs sector, with respect to the new scenario brought by the emergence of CCUS. At the end of this prospective analysis of the entanglement of PPs and PRs in the current situation, we will therefore be able to evaluate the adequacy between the existing institutional and legal provisions on one side, and the goal to regulate and encourage the development of CCUS in Switzerland on the other. We will conclude by presenting the changes that we would need to make in such provisions if we wanted to create a coherent and integrated legal framework for CCUS activities, in the form of recommendations for policymakers .

In part I, we use the IRR approach to investigate whether the current institutional and legal framework is adequate to effectively regulate the development of CCUS in Switzerland. This part is organized as follows:

- chapters 1 and 2 clarify the circumstances which allow to confer the legal status of "natural resource" to carbon dioxide, in order to justify the use of the IRR approach to subsequently investigate the sustainable use of CO_2. Such sustainability needs to be analyzed not only with respect to the renewal capacity of the resource CO_2 but also with respect to the preservation of the natural resource 'climate', which is modified by CO_2 emissions. We interpret a number of provisions contained primarily in the Environmental Protection Act (EPA), the most important environmental protection law in Switzerland, and in the Swiss Civil Code, to deduce the current legal status of carbon dioxide as it results from these pieces of legislation, which contain most of the legal definitions which can apply to CO_2 in the context of CCUS processes. We then compare the Swiss case with the European one, a possible source of inspiration for the redefinition of the legal status of the CO_2 in chapter 10;

- in chapter 3, we introduce the main concepts of the IRR analytical framework from a theoretical perspective, according to the existing literature on this topic (see e.g. Gerber 2006; Gerber et al. 2009; P. Knoepfel et al. 2003);

- in chapter 4, we define the natural resource under exam, carbon dioxide, and its perimeter according to physical criteria; then we identify the uses and users of the resource as well as the possible rivalries which can surge as a result of the competition over the resource;
- in chapter 5, we use the IRR approach to analyze the opportunities related to CCUS which are offered by the current formulation of the PPs, i.e. the so-called politico-administrative programme (PAP), and the PRs system in private law related to the ownership and the use of carbon dioxide. The main scope of such an investigation is to determine the degree of sustainability of the use of CO_2 in CCUS processes in the existing legal framework, which was not designed *a priori* for CCUS applications, at least at the Swiss level. However, we realize that the current regulations, even if do not mention explicitly CCUS technologies, contain a certain number of provisions that would apply quite straightforwardly to a possible large-scale industrial and commercial deployment of CCUS;
- in chapter 6, we deal with the analysis of the basic triangle of the policy actors in the context of the institutional regime of carbon dioxide. We also discuss the impacts that the current regime can have on the use of the resource through CCUS applications and the changes of the regime over different phases of the evolution of the regime over a long period of time, from a prospective viewpoint;
- in chapter 8, we conclude our analysis of the IRR by evaluating the main gaps and inconsistencies of the current institutional regime relative to CCUS development. In this way we lay the foundations for a comprehensive proposal of modifications of the regime currently regulating the use of the resource ‘carbon dioxide’, with the goal of creating an IRR of carbon dioxide which can regulate and stimulate the development of CCUS in Switzerland in an effective way.

For what concerns the Swiss context, it is important to point out that our analysis involves the PAP which has been in force for a number of years at the time of this writing: hence, it does not deal with the most recent revision of the CO_2 Act, which is being discussed by the Federal Assembly as of 2019. The CO_2 Act considered here is therefore the 2011 version. However, the vast majority of the policy analysis and proposals exposed throughout this volume could easily be also applied to the revised version, since the proposed revisions, if accepted, would not change significantly the structure of the PAP having a possible impact on the deployment of CCUS in Switzerland.

In part II, we rely on the analysis conducted in Part I to present a series of recommendations for Swiss policymakers to facilitate the development of CCUS.

This volume also includes two appendices:

- appendix A includes a collection of the most relevant technical definitions, acronyms and legal provisions used throughout this volume;
- appendix B replicates the inventory of the CO_2 emissions in Switzerland for the year 2016 already introduced in volume 1, chapter 3.

Throughout this volume, for each legal provision that we explicitly quote, we reproduce its English version that can be found on the internet portal of the Swiss government, even though such a translation is generally provided for information purposes only and has therefore no legal force. The translation in English of the provisions for which the English version does not already exist is made by the author.

PART I: THE IRR OF CCUS

A thorough analysis of the legal status of captured and stored CO_2 and captured and utilized CO_2 has not been conducted to date. In general, legal academic research has given very little attention to CCUS technologies (a recent exception being Favre and Largey 2017). Nevertheless, the legal status of carbon dioxide needs to be addressed in the perspective of the multiple pathways that CO_2 can possibly undergo in the context of an anthropogenic carbon cycle with CCUS technologies and its importance in climate policies. The clarification of the legal status of carbon dioxide as a natural resource will also allow to apply in a coherent manner the theoretical framework of the Institutional Resource Regime (IRR) to the study of the regulations governing the use of this resource. This topic, constituting the centerpiece of this volume, will be thoroughly examined in the following chapters.

While one could discuss the need to understand/identify the actual legal status of CO_2 in the context of CCUS development within the limits of one single country's institutions and policies, given the supranational nature of climate change, it is also true that the largest bulk of legal provisions addressing climate change is produced at the national level. In other words, the fundamental political weakness of international agreements and organizations dealing with climate change[1] means that most of the legally binding content in these policies is effectively provided, in large part, by provisions enacted at the state level and framed by the international treaties. Legal status of CO_2 and public policies which are related to climate change are interconnected: on one hand, a number of existing provisions and regulations on waste, natural resources or air pollutants could possibly concern carbon dioxide provided that the actual legal status of CO_2 is correctly understood in the current institutional and legal framework; on the other hand, it is the same set of provisions which provides the instruments for such an identification, i.e. for a classification of CO_2 as a waste, a resource or a pollutant according to the circumstances. Therefore, the coherence of these public policies closely

[1] *For instance, the landmark 2015 Paris Agreement is characterized by a lack of binding enforcement mechanisms.*

reflects the level of consistency in the legal status of carbon dioxide, and vice versa; the integration between these two aspects hence represents an important goal to pursue.

1 SOME LEGAL DEFINITIONS: WASTE, AIR POLLUTION AND RESOURCES

We begin our analysis by looking at the Swiss Environmental Protection Act (EPA) of 1983, where "waste" is defined as "[...] any movable material disposed of by its holder or the disposal of which is required in the public interest" (art. 7 par. 6 *EPA* 1983) and "air pollution" on the other hand is defined in the same Act as a "modification of the natural condition of the air, in particular, through smoke, soot, dust, gases, aerosols, steams, odors or waste heat" (art. 7 par. 3 *EPA* 1983).

Another important concept is that of "natural resource", for which there is currently no unanimously accepted legal definition. However, such an expression is largely employed in countless legal texts: for instance, art. 2 let. 4 of the Swiss Constitution states that the Confederation "is committed to the long term preservation of natural resources [...]". According to the approach by Nahrath and Gerber, an element (material or immaterial) of the natural environment becomes a natural resource when it is mobilized by a productive system of goods and services (Nahrath and Gerber 2014). This fundamental concept of relationship between the natural environment and a productive system in the definition of a natural resource is actually at the basis of art. 73 of the Federal Constitution (*Federal Constitution* 1999), which provides the fundamental principle which guides Swiss environmental legislation: "the Confederation and the Cantons shall endeavour to achieve a balanced and sustainable relationship between nature and its capacity to renew itself and the demands placed on it by the population". Hence, this principle of sustainability explicitly evokes on one hand the utilization of natural resources by the human beings and, on the other side, the equilibrium between human beings and nature, that is, the relationship between the elements of nature and their human exploitation. In a legal perspective, a natural resource can also be defined, according to Largey 2017, as "a material or immaterial element of the natural environment whose uses of goods and ecosystem services provided by a production system - intended to meet the needs of either human beings or other living beings - are governed by legal operating standards designed to ensure its sustainable conservation". Formulated from the perspective of the human being/user, the natural resource designates "a material or immaterial element of the natural environment on which user rights may be exercised in order to benefit from ecosystem goods and services through a process of connection with a production system, while guaranteeing its conservation".

These three definitions of waste, air pollution and natural resource constitute the basis for our evaluation of the legal status of the CO_2..

2 THE LEGAL STATUS OF CO_2 IN THE CONTEXT OF CCUS

2.1 SWISS LEGAL STATUS

The concrete and corpuscular existence of the atmospheric matter such as carbon dioxide allows it, in certain circumstances, to become the object of actual legal rights. Art. 7 par. 6 *EPA* 1983 connects the concept of “waste" to the concept of “movable material” or “movable thing” (Wagner Pfeifer 2017), namely “concrete, circumscribed, impersonal and appropriable objects that can be moved from one place to another” (Largey 2017) and which, according to art. 713 of the Swiss Civil Code (*Swiss Civil Code* 2006), can be subject to chattel ownership. If we follow for the elimination of CO_2 the principles described in art. 30 *EPA* 1983, which establishes a hierarchical order for the avoidance and disposal of waste, we can conclude that CO_2 can be viewed as “waste” only when it can also be considered as a “movable material”, that is, when the holder of a volume of this gas, delimited by a container, gets rid of it in the underground or into the atmosphere (cf. art. 7 par. 6 *EPA* 1983). However, its status of “waste” is lost at the moment of its spreading, simultaneously with the loss of its legal status of “movable thing”, or at the moment of its valorization through CCU technologies, when it acquires the status of “resource”. In this last case, since it will replenish, both naturally through the natural carbon cycle and artificially through the anthropogenic carbon cycle, in a finite amount of time in a human time scale, to replace the portion depleted by such valorization, carbon dioxide is more precisely a *renewable resource*. It can similarly be regarded as a *renewable waste* when it has the status of waste, cf. above, since it is waste that can be recycled.

The carbon dioxide produced by human activities, as well as the gas of natural origin present in the atmosphere, is therefore at the same time (under certain aspects) waste (that the individuals wish in principle to get rid of) and a resource. In particular, it is waste to store when dealing with CCS technologies, and waste to valorize as a resource when dealing with CCU technologies[2].

This can be clearly seen in the case of DAC, in which the status of the CO_2 which is captured directly from air depends on its destination: when the CO_2 is valorized in a CCU process, it is a resource; when the CO_2 is captured in a CCS process to be safely stored in a geological reservoir, it is waste that society as a whole is trying to get rid of, similarly to waste disposal in landfills.

We stress that CCU techniques are in complete agreement with the spirit of art. 73 of the Swiss Constitution on sustainable development, which contains at its core the principles of recycling renewable resources and of a circular economy. In other words, the peculiar nature of CO_2 which can be both waste and resource allows to put in advance the concept of recycling as a fundamental process in the sustainable development scenario. Moreover, art. 74 of the Swiss Constitution on the protection of the environment indirectly supports, in par. 1, the development of legislation on both CCS and CCU, since it gives the Confederation a mandate to "legislate on the protection of the population and its natural

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2 *One could also discuss whether the carbon dioxide which is captured e.g. at the tailpipe of a fossil fuel power station is actually a natural resource or rather an anthropogenic resource, since it is a direct product of human activities conducted in the Anthroposphere. Actually, the United Nations Framework Classification for Resources (UNFC) classifies anthropogenic resources as stocks that are found in the Anthroposphere, which are usually denominated as "wastes" but which constitute "a concentration or occurrence of Anthropogenic Material of intrinsic economic interest, in such form, quality and quantity that there are reasonable prospects for eventual economic exploitation" (UNECE 2018). This shows that for carbon dioxide as a flue gas, the designation of "anthropogenic resource" would actually be an indication of the aforementioned double nature of CO_2 in the productive system - both waste and resource. In this perspective, and given that carbon dioxide which can be mobilized by CCU processes in the productive system can be both airborne or a flue gas and that the two forms are physically and chemically indistinguishable, we will not refer to the term "anthropogenic resource", to which we prefer the equivalent expression of "renewable waste", that is, waste that can become a resource.*

environment against damage or nuisance", where the term 'nuisance' designs, according to the language of the Environmental Protection Act (EPA), harmful effects on "people, animals and plants, their biological communities and habitats" (see art. 1, par. 1 *EPA* 1983), a description which clearly suits the effect of anthropogenic CO_2 emissions on the global climate. Art. 74, par. 2 also plaids for the avoidance of such nuisance, which for CO_2 translates in prevention, reduction or capture of anthropogenic emissions.

2.1.1 CO_2 AS RESOURCE

To our knowledge, the legal relationship between "resource" and "movable thing" has not been examined, given that there is currently no unanimously accepted legal definition of "resource", as we said before. However, conforming to the concept of movable thing as contained in the Swiss Civil Code (cf. art. 713 *Swiss Civil Code* 2006), the status of movable thing is compatible with some of the "elements" described in the definition given in Nahrath and Gerber 2014. More precisely, immaterial elements of the natural environment, for example the wind, are not clearly circumscribed and cannot be moved at will from one place to another, whereas material elements such as atmospheric matter, water or coal are either intrinsically movable things (e.g. water, coal, copper, etc.) or become movable things under certain conditions, namely whenever they are delimited by a recipient (e.g. atmospheric matter such as CO_2). This property actually allows them to be "mobilized" according to the definition of "resource" given by Nahrath and Gerber 2014. Therefore, immaterial elements of the natural environment such as the wind which can never be "movable things" are natural resources since they can be exploited and valorized by a productive system of goods and services. On the other hand, material elements such as the atmospheric matter are movable things whenever are mobilized by the productive system, intrinsically or necessarily. Even atmospheric matter such as CO_2, however, is still a resource even when it is no longer contained in a recipient and therefore loses its status of movable thing, since it can potentially be captured and valorized. Therefore, the status of movable thing is somehow connected to the status of natural resource only for material elements of the natural environment, in the sense that it is only when they are movable things that the material elements can concretely be mobilized as resources by the productive system.

2.1.2 CO_2 AS A POLLUTANT

In this section, we discuss the possibility to consider carbon dioxide as a pollutant on a legal basis. While the status of "air pollutant" would seem to be the most appropriate one, the options "soil pollutant" and "water pollutant" are also worth investigating in the context of CCS. In fact, the injection of carbon dioxide in large underground reservoirs can alter the physical and chemical properties of these reservoirs as well as the underground aquifers, a fact that could potentially lead this CO_2 to fall into the category of "soil pollutant" or "water pollutant" according to certain laws.

Soil pollutant. According to art. 7 par. 4bis *EPA* 1983, "soil pollution is the physical, chemical and biological modification of the natural condition of the soil. Soil means the unsealed top layer of land where plants may grow". Therefore, the carbon dioxide which is captured and stored underground in a reservoir does not constitute soil pollution according to this definition, since such reservoir is well below the top layer of land.

Water pollutant. Art. 4 let. d of the Federal Act of 24 January 1991 on the Protection of Waters (Waters Protection Act, WPA) defines water pollution as "any detrimental physical, chemical or biological change in the nature of waters". In such respect, given that the injection of carbon dioxide in the proximity of underground aquifers leads to the formation of carbonic acid, which can dramatically compromise safe drinking water supplies (Fogarty 2010), the CO_2 stored underground as in CCS can potentially become a water[3] pollutant. However, in the absence of such a leakage the CO_2 which is stored underground cannot acquire this status.

Air pollutant. According to the aforementioned art. 7 par. 3 EPA 1983, CO_2 emissions that are attributable to the use of fossil fuels as energy sources also qualify to the legal status of "air pollutant" when released into the atmosphere, since they constitute an artificial alteration in the composition of the atmosphere. We can note that at this stage no commentaries about their harmfulness or their impacts on the environment or human health enter the definitions of waste or air pollution. However, art. 1 *EPA* 1983 specifies that the EPA "is intended to protect people, animals and plants, their biological communities and habitats against harmful effects or nuisances and to preserve the natural foundations of life sustainably, in particular biological diversity and the fertility of the soil" and that "early preventive measures must be taken in order to limit effects which could become harmful or a nuisance", thereby connecting the necessity of a public intervention to excessive and harmful levels of emissions of waste and air pollutants. Art. 7 par. 2 *EPA* 1983 specifies that "air pollution, noise, vibrations and radiation are referred to as emissions when discharged from installations, and as ambient pollution levels at their point of impact": in the case of CO_2, this means that we can talk about CO_2 end-of-pipe emissions when they are discharged from a fossil fuel power plant, a cement plant, a petroleum refinery, etc., and about CO_2 concentration level in the atmosphere or in the oceans, which is where anthropogenic CO_2 has its impact in terms of the greenhouse effect. And even if an explicit definition of anthropogenic CO_2 emissions as air pollutant is absent from the 2011 CO_2 Act or from the 2012 CO_2 Ordinance, the connection between CO_2 and air pollution is made e.g. in the Federal Council Dispatch of 26 August 2009 relative to the Swiss climate policy after 2012, which explicitly mentions the application of the "polluter pays" principle to finance CO_2 emission reduction measures (*Dispatch relative to the Swiss climate policy* 2009). This principle is

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[3] *In this specific case, underground water.*

firmly stated both in art. 74, par. 2 of the Swiss Constitution and in the Swiss environmental legislation, first of all in art. 2 *EPA* 1983, see appendix A. A detailed review of the main arguments which support the inclusion of carbon dioxide in the list of air pollutants can be found on pp. 18 ff.

The case in which the CO_2 captured from the air is safely stored instead than valorized is actually not economically profitable: however, it can still make sense under a purely environmental perspective. Since currently the levels of CO_2 in the atmosphere are way higher than they were just before the Industrial Revolution because of anthropogenic emissions of this gas and since the harmfulness of these emissions to the Biosphere is universally recognized, they qualify to the legal status of air pollutant according to art. 7 par. 3 *EPA* 1983. In fact, "air pollution" according to art. 7 par. 3 ("modification of the natural condition of the air, in particular, through [...] gases [...]", which can describe the action of anthropogenic CO_2 emissions) is one of the "effects", which could become harmful and against which the EPA is intended to act, listed in art. 7 par. 1 *EPA* 1983.

Moreover, since the harmfulness of these emissions to the Biosphere is recognized, they have to be "limited by measures taken at their source (limitation of emissions)" (art. 11 par. 1 *EPA* 1983). While the public necessity of measures to decrease the concentration of this air pollutant in the air as described in this paragraph is clearly consistent with the finalities of DAC, the fact that DAC limits air pollution by intervening only after the substance has been released in the air shows that the EPA of 1983 is today inadequate to describe and regulate the totality of the current landscape of CCUS technologies meant to counteract the increase of CO_2 concentration in the atmosphere. Therefore, an integration of this law to legally recognize the environmental finalities of some of the most recent technologies appears necessary.

Is CO_2 an air pollutant?
As it can be seen in this section, the legal status of carbon dioxide is very complex in the light of its multifaceted role in the natural

environment: it is at the same time, in fact, a naturally occurring component of the atmosphere among many others, an indispensable element for the sustenance of life on this planet through the carbon cycle, and the main responsible for the greenhouse effect which drives anthropogenic climate change. For this reason, its status as air pollutant has long been debated, sometimes for political motivations. We find however that there are multiple reasons to consider carbon dioxide as an air pollutant. The fact that it can be naturally found in nature does not certainly mean that it cannot be harmful, as the same thing is true for other air pollutants, for instance sulfur dioxide (a toxic gas which is also released naturally by volcanic activity). While the natural carbon cycle has maintained the levels of CO_2 in the Earth atmosphere at a global average of 280 ppm[4], the anthropogenic carbon cycle which began during the Industrial Revolution in the 18th century has currently brought this level to more than 400 ppm, without mentioning the fact that today's rate of increase is more than 100 times faster than the increase that occurred when the last ice age ended. Therefore, while it is true that naturally occurring carbon dioxide is essential for the sustainment of life, anthropogenic CO_2 emissions caused by industrial activities and fossil fuels burning are the main force behind the anthropogenic greenhouse effect which threatens public health and life as we know it in a potentially destructive manner if left unchecked.

Undoubtedly carbon dioxide occupies a separate niche from the other traditional air pollutants (*OAPC* 1985). In fact, "for standard pollutants, it makes sense to seek to drive them as close to zero as is feasible. With carbon dioxide, this strategy is profoundly destructive to all living things" (Epstein 2010). Therefore, when carbon dioxide becomes a pollutant necessarily depends upon the quantities of the gas found in the atmosphere, since excessive amounts of it could trigger a process with potentially negative consequences. "The more crucial question is what threshold concentration of carbon dioxide would

[4] *During the 800,000 years before the Industrial Revolution, CO_2 fluctuated between about 180 ppm during ice ages and 280 ppm during interglacial warm periods.*

trigger such catastrophic events [...]. The battle then is about how much carbon dioxide should be allowed, not whether it should be allowed at all" (Epstein 2010).

In this perspective, it makes sense in a legal setting to consider pre-industrial levels of carbon dioxide in the atmosphere as level zero (or as close to zero as possible) of standard air pollutants in the atmosphere: an ideal, desirable situation to strive for. Given this point, it is interesting to notice that the current policies which aim to mitigate climate change would likely need to be reversed if somehow we found ourselves in the opposite situation, with too low concentrations of carbon dioxide in the atmosphere: in this case the CO_2 would completely lose its possible status as an air pollutant and it would become a precious resource, not to be inserted into an economically profitable production process such as CCU, but to be emitted in the atmosphere with the goal to bolster Earth's greenhouse effect, an action which in such a situation could become critical to supporting life as we know it. Of course, this line of reasoning remains largely abstract in the current situation in which even a small decrease in atmospheric CO_2 concentration will be a very difficult political and economic task.

At the policy level, the similarity existing between CO_2 as an air pollutant and other air pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NOx), which are commonly known to cause acid rains, is illustrated by the fact that they have been regulated in history by the same emissions trading system which had been specially designed for air pollutants reduction. The economic principles behind trading in emissions of air pollutants were first explained by American economist Thomas Crocker in his 1966 essay "The Structuring of Atmospheric Pollution Control Systems" (Crocker 1966) and by Canadian economist John H. Dales in his 1968 landmark book "Pollution, Property, and Prices: An Essay in Policy-Making and Economics" (Dales 1968). The U. S. Acid Rain Program, implemented through the Clean Air Act amendments of 1990 and run by the U. S. Environmental Protection Agency (US EPA), established the first large-scale practical application of an emissions trading system following closely the propositions by Crocker and Dales, to reduce emissions of SO_2 and NOx, mainly by electric power plants, in the United States. This program proved to be highly effective and was emulated by the EU ETS which was established in 2005 by the EU to regulate GHG emissions, in response to the goals set by the Kyoto Protocol of 1997.

There is an additional peculiar aspect of carbon dioxide which distinguishes it from the other, traditional air pollutants: namely, that while the effects of the latter are local and therefore the localization of the emission spot can have important repercussions on human health, the effects of the former on the Earth's climate are global, making such localization irrelevant. This issue will be further discussed in chapter 10.

It is also interesting to notice that some regulations currently exist on the maximum allowed indoor concentration of carbon dioxide in order to avoid the toxic effects of dangerous levels of CO_2. Ambient air in a room is generally considered to be safe for human health when the overall CO_2 concentration does not exceed 1000 ppm throughout the period of use of the room. This limit value, called the *number of Pettenkofer*, applies to all work and living rooms. Therefore, well before anthropogenic climate change brought to the general attention the danger caused by carbon dioxide as a GHG, it was well known that dangerous indoor levels of CO_2 made it an air pollutant. Since this form of pollution is completely unrelated to the issue of climate change mitigation, it will not be further discussed, even though it is connected to one of the main issues related to CCS. In fact, unintentional leakages of large amounts of CO_2 from underground reservoirs into the atmosphere would pose significant threats for asphyxiation to humans and animals in the surrounding locations: there are a number of documented cases reporting human fatalities in atmospheres of elevated carbon dioxide concentration, cf. Harbison et al. 2015.

Ultimately the political implications involving a decision on the inclusion of CO_2 in the wide class of air pollutants are strong and can play a role in such a recognition. That being the case, the landmark 2007 opinion of the U. S. Supreme Court in the case *Massachusetts v. EPA* which recognized the authority of the US EPA to regulate tailpipe emissions of carbon dioxide and other GHGs under the Clean Air Act (CAA) commenting that "greenhouse gases fit well within the CAA's capacious definition of air pollutant" (*Massachusetts v. EPA* 2007), albeit a legal ruling in its foundations, is also in part a political one.

It is also worth noticing that art. 13 par. 1 *EPA* 1983 on the ambient limit values[5] of harmful substances ("The Federal Council stipulates by ordinance the ambient limit values for assessing harmful effects or nuisances") could also apply to CO_2. In fact, even though the Federal Council has never enacted actual ambient limit values for CO_2 concentration in the atmosphere (to be measured in ppm), in the CO_2 Act of 2011 (*CO_2 Act* 2011) both a target of limiting the global rise in temperature to less than 2 degrees Celsius (art. 1 par. 1 *CO_2 Act* 2011) and a target of an overall reduction of domestic greenhouse gas emissions (included carbon dioxide) by 20 per cent as compared with 1990 levels by 2020 (art. 3 par. 1 *CO_2 Act* 2011) are present. All these limits could in principle be translated, and therefore interpreted, as ambient limit (concentration) values on atmospheric carbon dioxide as well as other GHG. On the other hand, in the transportation sector, art. 10 of *CO_2 Act* 2011 fixes limit values for the CO_2 emissions from vehicles and these emission limit values (ELVs), i.e. the maximum intensity of pollutant emissions allowed per emitter during a given period (concentration and flow), are not directly connected to ambient limit values (Nahrath and Gerber 2014).

[5] *By ambient limit value (ALV), we mean the maximum average concentration allowed for a polluting substance in a particular environment and during a given period. ALVs are thus the more or less specific objectives to be achieved by the different environmental policies (Nahrath and Gerber 2014).*

The Ordinance on Air Pollution Control of 16 December 1985 contains a provision that is actually fitted for CCUS too, stating that "emissions shall be captured as fully and as close to the source as possible and shall be removed in such a way as to prevent excessive ambient air pollution levels"[6] (art. 6 par. 1 *OAPC* 1985). Capture of CO_2 is clearly concerned by this legal provision, which is clearly best suited for tailpipe emissions but could also apply to other means of capture such as DAC. It is important to stress that CO_2 capture alone does not tell us anything about the specific form of subsequent storage or utilization of carbon dioxide. However, only a long-term storage in the case of CCS allows to consider it to have been removed "in such a way as to prevent excessive ambient air pollution levels", consistently with art. 6 al. 1 *OAPC* 1985. It is usually considered that a leakage of 1% or less of stored CO_2 in a hundred years would be an acceptable value (Shaffer 2010).

For what concerns CCU, the matter is even more complicated, since the different possible valorization paths of the captured carbon dioxide have in general different global warming potentials and this could drastically change the life cycle carbon balance of the whole CCU process. In particular, the final products of the valorization of the captured CO_2 usually release CO_2 after their utilization. One should therefore check whether the specific carbon balance covering the whole CCU process and the lifetime of a specific product corresponds to an actual reduction of carbon dioxide emissions compared to the case in which the same product would have been made from fossil resources. In other words, net carbon reductions may be achieved when the products of a given pathway replace a more carbon-intensive alternative.

[6] *However, it should be noted that the Ordinance on Air Pollution Control does not explicitly list CO_2 among the air pollutants which are subject to the provisions of* EPA *1983. Indeed, this ordinance focuses on more traditional, toxic air pollutants and is not intended to address the issue of climate change mitigation.*

2.1.3 CO_2 AS WASTE

The peculiar situation of CO_2 in Swiss public law illustrates the limitation inherent in the connection of the status of "waste" to the status of "movable thing" in civil law. Because of this rigid legal concept, the legal scholar is confronted to some problematic inconsistencies: for example, the carbon dioxide stored before being released into the atmosphere is considered as waste, whereas the CO_2 which passes through a chimney before being directly emitted is not. Therefore, it would be appropriate to base the legal regime of waste not on the delimitation or the corporeality of the element that must be disposed, but the functions and the objectives connected with the waste. In this way, one would be able to treat not just CO_2, but all the air pollutants of anthropic origin, as waste, without having to inquire whether a muffler or a chimney constitutes a container delimiting a fungible thing. In this sense, given that public interest commands the elimination of the CO_2 or any other air pollutant which escapes through the muffler or the chimney, this gas acquires the status of waste and hence it must follow the requirements described in art. 30 ff. *EPA* 1983 concerning waste avoidance and disposal, as well as the necessity of the limitation of its production (Largey 2017).

2.2 EUROPEAN LEGAL STATUS

As a useful comparison, we present here briefly the main aspects of the legal status of CO_2 that can be deduced from a number of EU Directives. A more comprehensive analysis of the existing EU legislation concerning CCUS is provided in section 5.1.2.

2.2.1 CO_2 AS WASTE

In European law, the Directive 2008/98/EC of the European Parliament and the Council of the European Union of 19 November 2008 (also known as "Waste Directive") defines "waste" as "any substance or object which the holder discards or intends or is required to discard" (art. 3 par. 1 *Directive 2008/98/EC* 2008). This definition is characterized by a wider field of application than the one in the Swiss public law and it corresponds to a legal definition which could be more suitable to CO_2 emissions. Moreover, the same Directive specifies that waste shall cease to be waste when "it has undergone a recovery, including recycling, operation" (art. 6 par. 1 *Directive 2008/98/EC* 2008) and complies with specific conditions listed in the same paragraph (Largey 2017).

However, the Waste Directive explicitly excludes carbon dioxide of anthropic origin or, more broadly, "gaseous effluents emitted into the atmosphere", from its scope (cf. art. 2 par. 1 let. a *Directive 2008/98/EC* 2008). Therefore, the notion of "waste" according to this Directive does not legally applied to anthropic CO_2 emissions, nor for CO_2 which is captured and stored underground. The latter is indeed explicitly regulated not by the Waste Directive, but by the Directive 2009/31/EC of 23 April 2009, or "CCS Directive".

2.2.2 CO_2 AS A POLLUTANT

Air pollutant. Art. 2 par. 2 of the Directive 2008/1/EC of 15 January 2008 (also known as "Integrated pollution prevention and control Directive", or "IPPC Directive") defines "pollution" as "the direct or indirect introduction as a result of human activity, of substances, vibrations, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment". This is a definition which is suitable to CO_2 emissions associated with human activities that involve the burning of fossil fuels and cause anthropogenic climate change. However, Annex II of the Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions ("Industrial Emissions Directive"), which lists all air polluting substances which fall under the scope of the Directive, does not include carbon dioxide. This reminds of the Swiss legislation, in which the Ordinance on Air Pollution Control does not explicitly list CO_2 among the pollutants which are subject to the provisions of *EPA* 1983. Indeed, these laws generally target more traditional, toxic pollutants as they were not originally intended to address the issue of climate change mitigation. Yet, as we have shown here, there are no fundamental impediments in the current legal framework in what concerns the possible attribution to CO_2 of the legal status of air pollutant.

Land and water pollutant. Interestingly, the definition of "pollution" contained in the IPPC Directive could also be applied as such to carbon dioxide which is stored in reservoirs, as in CCS, since (as we have already said) unintentional releases of carbon dioxide from underground reservoirs as in CCS could potentially be hazardous for human health, the environment and the drinking water supplies (Fogarty 2010). Contrarily to the case of the Swiss legislation examined above, the IPPC Directive does not contain a restrictive definition of land, therefore the carbon dioxide which is stored underground could potentially become a "water pollutant" or even a "land pollutant", but only if, as specified in the Directive, it is proven to be "harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment". While it would be relatively easy to relate the pollution of water to its acidification due to the leakage of carbon dioxide, the possible pollution of land due to carbon dioxide injection is a subject that does not lay on any legal basis so far.

2.3 SUMMARY OF SWISS AND EUROPEAN LEGAL STATUS OF CO_2

In conclusion, in Swiss public law,

- the carbon dioxide which is produced and then captured and safely stored through CCS technologies satisfies to the definition of *waste*, cf. art. 7 par. 6 and art. 30 *EPA* 1983; if it contaminates underground drinking water supplies, it becomes a *water pollutant*;
- the carbon dioxide which is produced and then rejected into the atmosphere constitutes *waste* as well, but only until the very moment

of its spreading, when it loses its status of waste to become an *air pollutant*, cf. art. 7 par. 3 *EPA* 1983.

Our analysis has also shown that, unofficially, we could regard the carbon dioxide which is valorized through CCU technologies as a *resource*.

Albeit the notion of resource does not clearly arise from specific laws or from the Civil Code, it comes from a practical reality which has so far not been directly covered by any laws, especially in the case of CCU for which no specific legislation has been passed yet. This reveals the need for the introduction in the federal legislation of an unequivocal definition of "resource" which should also encompass e.g. the CO_2 due to the possibility of its valorization through CCU processes.

We have also found that, according to European public law, carbon dioxide emitted into the atmosphere is not considered a waste, albeit the definitions included in the Waste Directive of 19 November 2008 would be comprehensive enough to allow it. A precise definition of *resource* is missing from the EU legislation, thereby complicating a possible discussion about the conditions under which CO_2 could acquire the legal status of resource. Instead, in analogy with the Swiss case, anthropogenic carbon dioxide emissions could be considered as an air pollutant, according to the IPPC Directive. Moreover, if the carbon dioxide stored in a reservoir underground contaminates water supplies nearby, it could be considered a water pollutant, according to the definition of "pollution" contained in the IPPC Directive.

In conclusion, the existing Swiss and EU legislation which can or could be applied to the implementation of CCUS processes as a climate change mitigation instrument, despite some similarities, have fundamental differences.

On one hand, the fundamental definitions of the concepts of waste and pollution in the Swiss legal framework, in particular in the Environmental Protection Act (EPA), are broad enough to include anthropogenic, or airborne captured, CO_2. In addition, the definition of sustainable development laid out in art. 73 of the Swiss Constitution fits perfectly CCU technologies in a perspective of circular, recycling economy, thereby supporting the recognition of CO_2 as a potential resource.

On the other hand, as we have seen above, while EU legislation defines pollution in a manner which is similar to the Swiss one and therefore is comprehensive enough to allow for the inclusion of carbon dioxide (as both air or underground water pollutant), existing EU provisions on waste explicitly exclude carbon dioxide from theirs scopes. EU lawmakers have rather preferred enact specific directives related to carbon dioxide in the context of the technical regulation of CCUS processes, cf. e.g. the CCS Directive or the ILUC Directive. This is in sharp contrast with the current Swiss situation, in which no specific provisions on CCS or CCU have been enacted so far.

Table 2.1 summarizes the current legal status of carbon dioxide both in the Swiss legislation and in the EU legislation. This table will be the starting point for our proposals about the legal status of CO_2 in Switzerland that we will present in chapter 10 taking into account the fact that CCUS technologies allow to widen the spectrum of the possible legal status of carbon dioxide. We will discuss whether the current existing legal description of CO_2 is adequate in the perspective of a massive deployment of CCUS technologies and whether some changes need to be proposed. We will focus on the legal status of CO_2 according to the Swiss public law, while referring to the European public law whenever useful.

Legal status of CO_2	*Waste*	*Resource*	*Pollutant*
CO_2 in the atmosphere	CH: No, since CO_2 in the air is not a movable thing (art. 713 Swiss Civil Code) and therefore it cannot constitute waste (cf. art. 7 par. 6 EPA).	CH: Yes. Even if a legal definition of resource does not exist yet, CO_2 can be considered as a natural resource since it can be captured and valorized in CCU processes, in the context of sustainable development as laid out in art. 73 of the Swiss Constitution.	CH: Yes when of anthropic origin, no otherwise (art. 7 par. 3 EPA).
	EU: No.	EU: A legal definition of resource does not exist yet and so far, only the ILUC Directive contemplates possible, limited uses of CO_2.	EU: Yes when of anthropic origin, no otherwise (art. 2 par. 2 IPPC Directive).
CO_2 stored as in CCS	CH: Yes (cf. art. 7 par. 6 EPA).	CH: No.	CH: It can become a water pollutant in case of contamination of water supplies.
	EU: No.	EU: No.	EU: It can become a water pollutant in case of contamination of water supplies.
CO_2 valorized as in CCU	CH: No.	CH: Yes (cf. *CO_2 in the atmosphere*).	CH: No.
	EU: No.	EU: Cf. *CO_2 in the atmosphere*.	EU: No.

Table 2.1: Overview of the legal status of CO_2 according to the existing Swiss and EU legislation.

3 INTRODUCTION TO THE IRR OF CCUS

The legal status of (renewable) resource acquired by the carbon dioxide which is produced, captured and then valorized through CCU technologies allows us to investigate the regulation of the complex and competitive heterogeneous (joint) use of this natural resource from a perspective of sustainability inside the theoretical framework of the Institutional Resource Regime (IRR), cf. P. Knoepfel et al. 2003. The IRR is a conceptual approach, whose name refers to the property rights (PR) to a resource and to the public policies (PP) regulating the use and protection of the resource, which enables the integration of policy analysis and property-rights theory (as a subsection of institutional economics) and considers all the elements of an environmental policy – i.e. resources, actors and institutional rules – into the same analytical framework. The IRR is based on the assumption that the two steering dimensions (policy analysis and property-rights theory) are complementary and that both must be considered simultaneously to facilitate the understanding of the actual uses made of the goods and services provided by a resource and to assess the degree of sustainability of these uses.

In this context, it is only possible to exploit the goods and services provided by a resource in a sustainable way if its reproduction capacity is not put at risk. In order to attain this goal, policies must undergo a fundamental change from a logic based on restrictions and limitations of pollutant emissions to a logic based on the balanced management of the stocks and reproductive capacities of resource systems. This goal "can only be attained, in turn, if all of the users jointly ensure that the quantities they extract or withdraw from a resource do not reach the limit of the reproductive capacity of the resource system" (Gerber et al. 2009). This can be done by setting clear limits for all appropriators and users on the extraction of good and services from the resource, or by encouraging them through new incentives to preserve it.

We believe that the IRR is a conceptual framework which is particularly adequate to analyze the deployment of CCUS in Switzerland. In fact, not only it allows to boost the new status of 'resource' of carbon dioxide in the perspective of the CCU roadmap, it also overcomes the limits of a sectoral approach to a public policy issue which is often incapable to recognize the interplay of policy regulations and actual property rights at work with that issue and the mutual influences between these two dimensions. This is especially true for the issues connected with the deployment of CCUS which require on one hand the establishment of new property rights for the CO_2 under the new economic and environmental paths offered by CCUS and, on the other hand, the unravelment of the multiple policies (industrial, fiscal, environmental, energy, etc.) involved in various manners in the CCUS processes and of their different, possibly contradictory relationships with the property rights of the CO_2. "By considering simultaneously the use rights rooted in property rights based on private law and in public policies, the IRR framework stresses their diversity but also demonstrates that they are closely linked. They are two faces of a same coin which together explain the regulation of the sustainable use of natural resource, the adequacy of which can vary. [...] Indeed the IRR framework can also be used normatively to propose more coherent regulations to policy makers" (Gerber et al. 2009).

It is worth noticing that, while an actual IRR analysis should be limited to the valorization of carbon dioxide as a resource, namely the CCU processes, and therefore should in principle exclude the storage of CO_2 from its perimeter, since CO_2 is not considered a resource in this case (as examined in chapter 2), we will sometimes consider CCS alongside CCU in this chapter since:

- an important part of the process (namely, the capture) is common to both CCS and CCU;
- both CCS and CCU represent competitive pathways for carbon dioxide and hence belong to the same analytical framework;
- at least one possible CO_2 utilization pathway - enhanced oil recovery (EOR) or, more broadly speaking, enhanced hydrocarbon recovery, see e.g. Table B.1 for more details - is sometimes considered to be

actually a CCS technique[7], therefore somehow blurring the conceptual difference between CCS and CCU.

Therefore, although strictly speaking we should conduct an IRR analysis of carbon dioxide as a resource only, our examination will span over the totality of the CCUS technologies for a more complete understanding of the valorization pathways of this resource.

In the circumstances of this IRR analysis, we also take into account the fact that the regulation of the use of the resource 'carbon dioxide' is strictly correlated to the sustainable preservation of another natural resource, the Earth's climate[8], since CO_2 happens to be the main driver of anthropogenic climate change and therefore behaves as a disruptor of the climate. In fact, the policy measures detailed in the following pages mainly concern the management of the carbon emissions as a means to preserve the resource 'climate'. Therefore, the IRR of CO_2 has to be meant as the ÌRR of the resource 'carbon dioxide' in the context of the protection of the resource 'climate'.

Alternative approaches to IRR

One could asks whether the IRR framework is the best instrument to analyze the regulation of the use of carbon dioxide. Actually, other analytical instruments exist, among which the Institutional Economics of Natural Resources approach and the Institutional Analysis and Development (IAD) framework (Gerber 2006):

1. The Institutional Economics of Natural Resources is based on the theory of property rights and it is one of the few analytical frameworks of the process of management of natural resources that focuses

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[7] *This specific technique is however very unlikely to have any application in Swiss territory in the foreseeable future due to the lack of vast oil and natural gas fields.*

[8] *To our knowledge, the first publication appraising climate as a natural resource is Landsberg 1946. It claims that the climate "is part of the natural endowment of a country. In some regions it imposes hardships on the inhabitants, in others it makes life easy". Having been written previously to the discovery of anthropogenic climate change, it contains outdated claims such as "at present the outdoor climate cannot be changed, except on the smallest scale".*

explicitly on the sustainability of the use of a natural resource by the human population, while at the same time highlighting the role of mediator of the institutions, governing the relationship between a society and the natural resources from which it depends.

2. The IAD framework is laid out in the general perspective of the "Institutional Rational Choice" approach, which is based on the assumption that any political decision process can be analyzed as an *interaction game* between rational individuals whose main goal is to maximize their utility function. The foundations of the IAD are therefore the institutional arrangements and their effects on the behaviors of rational but fallible individuals. These premises are integrated by two supplementary dimensions which constitute its specificity:

- the causal relationships existing between natural and social phenomena, i.e. the influence of the material characteristics of the natural and physical environment on the formation of institutional arrangements regulating all kinds of social activities
- the characteristics of the social community where the action takes place: standards of behavior, homogeneity of members, mutual trust, etc.

However, both these approaches, which are based on economic approach to the environmental policy issues, do not take sufficiently into account:

- the heterogeneity and the complexity of the various public policies involved at different levels in the regulation of the use of a natural resource, which can be sometimes in contradiction with each other
- the fact that the institutional framework is generally not fixed, but it needs to be considered as a component and a product of the political process, which thus can and has to change with time. A more dynamical approach is therefore necessary.

Therefore, the IRR framework, which favors a public policy approach, seems more adequate to analyze the regulation of the use of carbon dioxide, since it takes into account both the relationships between the various public policies involved in such a regulation and the temporal changes affecting the evolution of the resource as well as the public policies involved.

3.1 THE CONCEPT OF PROPERTY RIGHTS IN THE CONTEXT OF IRR

In Roman-Germanic legal systems, including the Swiss legal system, a clear distinction exists between public law and private law. *Public law* deals with the relationships between persons (i.e. individuals, business entities, non-profit organizations) and the state, including regulatory statutes, penal law and other laws that affect the public order. It constitutes the official embodiment of (one or more) public policies. *Private law*, on the other hand, is typically codified in a civil code and deals with relationships between individuals, e.g. the law of contracts, torts, property law, family law and inheritance law. It gives rise to the property rights system.

In general, provisions from both public law and private law create the various categories of rights that can exist on the property and use of a resource, which are not limited to the formal property rights but also include use rights.

Property rights are "the legal expression of the guarantee of access to a benefit stream in the context of a given legal, political and social order" (Gerber et al. 2009). They can only apply to a "thing", i.e. a material object. According to the Swiss Civil Code for example, "the owner of a thing has the right to use it freely, within the limits of the law" (art. 641 *Swiss Civil Code* 2006). An element of the world which has no material reality such as the landscape or the air cannot therefore be the object of such a right in the current legal order, even if there are, of course, indirect means of appropriation, e.g. through policies. Property rights are based on private law and thus last very long and are generally very stable. For instance, in Switzerland their definition is based on the Civil Code which has not fundamentally changed since its introduction in 1912.

On the other hand, *use rights* are attributed by public policies, which are based on public law, and can therefore be easily modified. However, use rights (including management and withdrawal rights) reflect formal property rights in the sense that they represent their concrete manifestation. "The definition of use rights often results from the combination of norms stemming from both private and public law. While private law establishes the basis for absolute ownership, public law tempers this absolute ownership by imposing restrictions on potential uses. Use rights are more specific than formal property-right titles in the sense that they usually concern only one good or service provided by a natural resource. Not all use rights however are rooted in formal property rights: they can also result from a policy which creates such rights and attributes them to beneficiaries that may not be legal owners. This situation is common in the case of resources for which no formal property rights exist" (Gerber et al. 2009).

Finally, *disposal rights* define the terms under which the formal property title of an object that is owned is transferred, i.e. selled, rented out, mortgaged, etc. While the disposal rights are normally rooted in formal property rights, in the sense that the person who has formal ownership of an object is also authorized to dispose of it, it is also true that the capacity of the owners to dispose of the object to which they hold the title can be limited by additional legal instruments rooted in public law, i.e. public policies (Gerber et al. 2009).

Fig. 3.1 provides a graphical representation of the different elements that make up an IRR and highlights the relationships that link them together. These elements are grouped in three main areas: the institutional regime of the natural resource under exam (the resource regime), the policy actors, and the natural resource itself.

3.2 EMPIRICAL RESEARCH PROCEDURE

We now apply the IRR framework to the resource 'carbon dioxide' by following the field research procedure in six steps as described in Gerber et al. 2009:

- *The resource*: this step simply provides the physical description of the resource and its perimeter according to physical criteria (not administrative boundaries).
- *Uses and rivalries*: this phase deals with the identification of the actual uses (in terms of goods and services) and users of the resource in the perimeter studied and analyzes the interactions between the various groups of users.
- *The resource regime*: this step should provide the "analysis, on the level of each good or service provided by the resource, of all regulations observable in either the relatively stable PR system or in changing PP, for the purpose of identifying existing (or non-existing) use rights attributed to specific user groups", as well as the "identification of ongoing changes of the extent and coherence of the IRR" (Gerber et al. 2009).
- *The implementation of the regime*: this step deals with the analysis of the interaction between the various groups of users of the resource CO_2 and the political-administrative authorities responsible for the regulation of the resource in order to highlight attempts to regulate rivalries over the use of the resource and institutional mechanisms of collective cooperation.

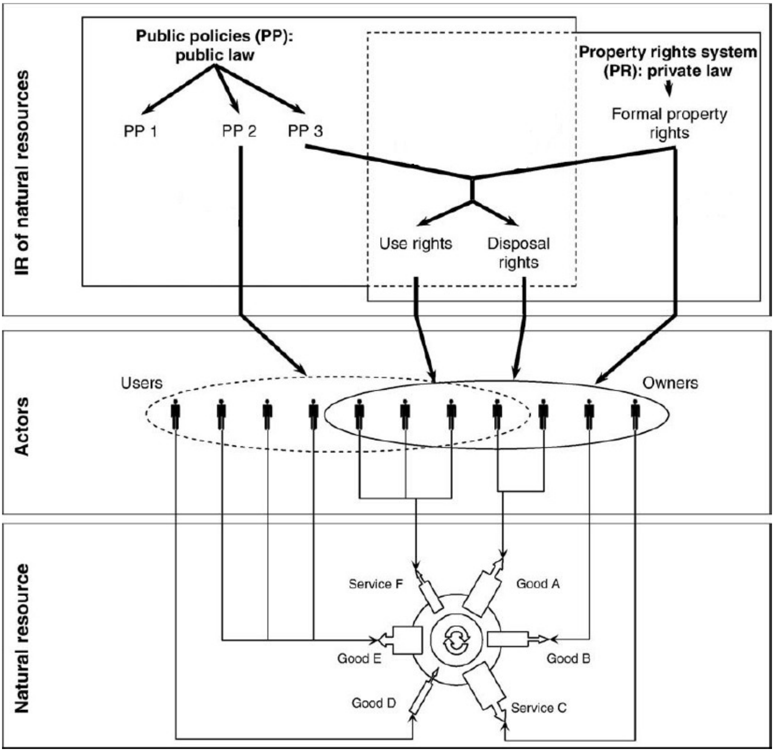

Figure 3.1: Regulation model highlighting the relationships between the Institutional Resource Regime (IRR), composed of a property-rights system (PR) and public policies (PP) (upper box), the actors who use the resource (middle box) and the condition of the resource (bottom box) as suggested by the IRR analytical framework.
The thickness of the arrows representing the goods and services provided by the resource is proportional to the intensity of their use (or restoration in the case of the arrow pointing toward the good D). In a sustainable use situation, the capital (stock) of the resource (central circle) is not affected by the overall use. Actors are influenced in their action vis-à-vis the resource by the rules in force, irrespective of whether they originate from PP or PR. Source: adapted from Gerber et al. 2009.

- *The impacts of the regime on the resource*: this step should provide the analysis of the level of sustainability of the use of the resource (reproduction capacity) and of the economic, ecological and social sustainability of the uses of the various goods and services derived from the resource (by means of commonly recognized indicators and related data).

- *Temporal changes*: repetition of the previous steps for the different phases of the evolution of the regime over a long period of time (sometimes up to hundred years).

Following this procedure, the next step is therefore the identification of users of the resource in the perimeter studied and the analysis of the interactions between the various groups of users.

4 THE RESOURCE, USES AND RIVALRIES

4.1 THE RESOURCE

Carbon dioxide, whose chemical formula is CO_2, is a gas which is a quantitatively minor (it represents only about 0.04% of the atmosphere's volume in dry air, excluding water vapor) but important constituent of the atmosphere on Earth and which is considered to be the main driver of the anthropogenic greenhouse effect in the atmosphere. CO_2 can be produced through both natural processes and human activities and it constitutes a renewable natural resource. The perimeter of the resource that we take into account is the Earth's atmosphere and the sinks, reservoirs and containers (both geological and artificial) where carbon dioxide can be stored for various lengths of time.

Detailed supplementary information about this resource, the carbon cycle and the greenhouse effect can be found in Volume 1 of this publication.

As previously mentioned, the resource 'climate' can be closely affected by the use of the resource 'carbon dioxide' via the greenhouse effect. Landsberg 1946 describes Earth's climate as a natural resource framing or supporting the use and enjoyment by human population of many other natural resources (water, food, wind, etc.). The influence that atmospheric carbon dioxide concentration has on the climate is a global one, therefore the localization of carbon sources is not important. As a consequence, the perimeter of the resource 'climate' that we consider is the whole climate systems, i.e. all of its five components: the atmosphere (air), the hydrosphere (water), the cryosphere (ice and permafrost), the lithosphere (Earth's upper rocky layer) and the Biosphere (living things), as well as the interactions between them (IPCC 2013).

4.2 USES AND RIVALRIES

In order to correctly identify the uses and rivalries which could possibly surge for the case of the resource 'carbon dioxide', we consider two perspectives which are different but complementary: CO_2 as a resource in itself, and CO_2 (emissions) as modification of another resource, the Earth's climate.

In the first case, the uses of CO_2 concern mainly CCU applications to the industry and the energy sector since, as we have seen in chapter 2, the legal status of 'resource' does not seem to describe correctly CO_2 when stored underground as in CCS. After its capture from either ambient air or from a concentrated source, the possible uses of the resource CO_2 (in terms of goods and services) as a feedstock material are multiple. They have already been presented in large detail and under different perspectives in volume 1 of this publication. We summarize them in Table B.1 which provides a classification of the diverse CCU applications.

In this context, the users of the resource 'carbon dioxide' are the companies involved in the manufacturing of all the products or the extraction of all the hydrocarbons that can be obtained from the captured CO_2 through the processes listed in Table B.1, as well as in the capture of carbon dioxide as e.g. in DAC.

In the second case, the role of CCU as a method to mitigate climate change is more nuanced since in general the impact on climate is diminished by the application of CCU technologies but not as much as what happens for the NETs, typically due to the release of CO_2 into the atmosphere at the end of the lifetime of the final product. On the other hand, CCS is a NET (see appendix A.1) and therefore plays a more direct role in the sustainable use of the resource 'climate'.

In this situation, the users of the resource 'carbon dioxide' are the companies or, more in general, the actors involved in the capture and the storage and/or the capture and utilization of CO_2. The users of the resource 'climate' which can be affected by the exploitation or the non-exploitation of the resource CO_2 are all the human beings and in particular the economic actors whose professional activity is strongly connected to climatic conditions. For instance, we can cite farmers, fishers, tourism operators, among many others.

In both cases, given the current abundance of carbon dioxide in the atmosphere and considering the urgent issues related to the greenhouse effect and the consequently benefits associated with the removal of certain amounts of CO_2 from the atmosphere, all the different possible uses of CO_2 included in CCUS, if enacted, are highly unlikely to lead to rivalries for the use of the resource in the short to medium term when considering DAC.

On the other hand, when considering carbon capture from a concentrated source (e.g. at the end of the tailpipe of a cement plant or a petroleum refinery plant), which is economically more attractive than DAC, the relative scarcity of these sources in Switzerland with respect to other countries could potentially lead to rivalries over the use of CO_2 between the different categories of users in a possible future in which proper economic and fiscal policies, technological improvements and environmental concerns have brought to a vast development of CCUS technologies. From an economic perspective, the best way to manage these rivalries would be to favor the most economically profitable CCU technology for the access to the resource from a specific concentrated source. From an environmental perspective, on the other hand, one should try to privilege the technologies with the lowest environmental impact.

However, since there are many different categories of environmental impact (such as global warming, land use, ozone depletion, acidification, human toxicity, etc.), ultimately there will probably be the need for comprehensive policy rules to evaluate and compare the different impacts, according to scientifically well-established cradle-to-grave life cycle assessments (see e.g. von der Assen et al. 2014 for an academic review on this topic), and it will be a political decision how to rank the impact category "global warming" with respect to the other categories in the context of CCUS. In conclusion, a combination of these two perspectives, economic and environmental, will probably be needed in order to discriminate in a politically judicious way between the various technologies in case of competition for the access to the resource CO_2.

A more detailed analysis of both the actors affected by a public policy on CCUS and the interactions between the different private actors and the political-administrative authorities responsible for the public policy, conducted with a more sophisticated conceptual tool such as the basic triangle of policy actors, will be presented in chapter 6, which deals with the implementation of the IRR.

5 THE RESOURCE REGIME

After this first glance at the users of recycled carbon dioxide and the rivalries that may arise from the commercial use of this resource, we analyze the regulations that govern the policy areas which are the most involved in a potential development of CCU or CCS techniques in Switzerland. We focus here on the existing regulations which, even if do not mention explicitly CCUS technologies, contain a certain number of provisions that would apply quite straightforwardly to a future large-scale industrial and commercial deployment of CCUS. These provisions are far from cover the totality of the different aspects involved in CCUS development, since as we previously said there is currently no officially established CCUS public policy in Switzerland. Hence, we will dedicate part II to a number of new legislative and regulatory proposals meant to define more precisely the means, the extent and the scope of a potential CCUS policy in the Swiss political and economic system.

5.1 PUBLIC POLICIES (PP): THE POLITICAL-ADMINISTRATIVE PROGRAMME (PAP)

The analysis of all the regulations observable either in the PR system or in the PPs, as well as the identification of use and property rights, can be carried out by looking at the political-administrative programme (PAP). The PAP includes *all of the legislative or regulatory decisions taken by both central state and public bodies and necessary to the implementation of the policy under exam* (Peter Knoepfel et al. 2007). We will therefore review all the legal provisions which can be used to identify the PAP of a CCUS public policy. We begin with the protocols and agreements existing at the international level, since these treaties play often a fundamental role in shaping the climate legislation at the Swiss level. We then deal with the provisions enacted by the European Union, which can constitute in some cases an interesting benchmark for the Swiss legislation. The last section of this chapter will be dedicated to the Swiss provisions.

5.1.1 THE INTERNATIONAL CONTEXT

Because of the very nature of climate, it has soon been clear that a coordinated transnational effort was the best and most effective way to deal with the roots of anthropogenic climate change. A network of international treaties and agreements lie at the foundations of the climate change mitigation policies which have been enacted worldwide since the end of the last century. The intergovernmental body of the United Nations responsible for shaping much of the processes leading to these environmental treaties from a scientific perspective is the aforementioned Intergovernmental Panel on Climate Change (IPCC), which was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) as a hybrid between a scientific body and an intergovernmental political organization to allow the international climate science community to take a stand in policy debates among the various political and economic forces at work (Bolin 2007). The official task of the IPCC is to provide the world with an objective and internationally accepted scientific view of climate change, its natural, political and economic impacts and risks, and possible response options. The IPCC has published along the years five comprehensive assessment reports on the latest findings of climate science, as well as a number of special reports on particular topics, complete with recommendations for policymakers, and acted as a main catalyst for a number of conventions, treaties and agreements which frame international climate change mitigation policy since 1992.

The United Nations Framework Convention on Climate Change (UNFCCC) of 1992

The goal of the United Nations Framework Convention on Climate Change (UNFCCC) of 9 May 1992, that was ratified by Switzerland on 10 December 1993, is to "stabilize [...] the concentrations of greenhouse gases (GHGs) in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system" (art. 2 *UNFCCC* 1992). The Convention defines a "reservoir" as "a component or components of the climate system where a greenhouse gas or a precursor of a greenhouse gas is stored" and a "sink" as "any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere" (art. 1 *UNFCCC* 1992), see also appendix A. In the perspective of the goal previously mentioned, States Parties are invited to take measures to reduce GHG emissions, but also to conserve and reinforce GHG sinks in accordance with art. 4, par. 1, sec. d of the Convention[9] (*UNFCCC* 1992).

Moreover, art. 4, par. 2, sec. a of the Convention stipulates that each of these States Parties "shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs" (*UNFCCC* 1992). This paragraph is written in a broad enough way to allow for the inclusion of anthropogenic geological reservoirs in the "GHG sinks and reservoirs" considered. Therefore, it provides a legal basis for CCS development as a way to mitigate global warming.

More in detail, the GHG emissions can be divided into the two categories of (1) *natural GHG emissions* and (2) *anthropogenic GHG emissions*; GHG sinks can analogously be separated into two groups, (3) *natural sinks* and (4) *artificial (or anthropogenic) sinks*. The Convention on Climate Change calls for a stabilization of the concentration of GHGs in the atmosphere and therefore for a balance between the emissions of GHGs and the uptake of GHGs by the sinks. One can get this either reducing emissions in category 2 or increasing sinks in category 4 while protecting the sinks in category 3. Before the introduction of CCUS technologies, only sinks in category 3 appeared on the 'sink" side of the balance, hence narrowing the stabilization opportunities to energy transition in category 2 and reforestation in category 3. The technologies of CCUS not only increase the number of options available in category

[9] *"All Parties [. . .] shall [. . .] promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems [. . .]".*

2[10], but also introduces the option of anthropogenic sinks, i.e. category 4. Some other techniques such as ocean fertilization, large-scale afforestation or enhanced weathering, on the other hand, enhance the uptake of carbon dioxide by natural sinks and can therefore be included in category 3.

In the Convention it is also stated that the Subsidiary Body for Scientific and Technological Advice (SBSTA) "[...] shall identify innovative, efficient and state-of-the-art technologies and know-how and advise on the ways and means of promoting development and/or transferring such technologies" (art. 9, par. 2 *UNFCCC* 1992) and this assures a clear way for CCUS to enter and take part in the toolkit of the technologies aiming at mitigation of anthropogenic climate change, even if CCS and CCU are not directly evoked.

In the framework of the UNFCCC, a Conference of the Parties (COP) takes place every year since 1995, gathering official representatives of all States that are Parties to the Convention that "review the implementation of the Convention and any other legal instruments that the COP adopts and take decisions necessary to promote the effective implementation of the Convention, including institutional and administrative arrangements" (United Nations - Climate Change 2018). The most important climate treaties were subsequently established at the COP 3 which took place in December 1997 in Kyoto, Japan, and at the COP 21 which took place in Paris, France from 30 November to 12 December 2015.

The Kyoto Protocol of 1997

The UNFCCC was extended in 1997 by the Kyoto Protocol (*Kyoto Protocol* 1997), an international treaty that commits state parties, included Switzerland, to implement the necessary reduction of GHG emissions following the principle of "common but differentiated responsibilities" (art. 10 *Kyoto Protocol* 1997). According to this principle, developed countries which have the historical responsibility for the current levels of

[10] *By replacing fossil resources for the manufacture of marketable products such as some chemicals.*

GHG in the atmosphere must carry the greatest share of efforts and have clear targets to reduce their emissions. They are listed as Annex I Parties under the Protocol. On the other hand, parties to the Kyoto Protocol not listed in Annex I of the Convention (i.e., the non-Annex I Parties) are mostly low-income developing countries: they are not submitted to the same legally binding emissions targets as the Annex I Parties, but they may participate in the Kyoto Protocol through the Clean Development Mechanism (CDM). The CDM is the first global, environmental investment and credit scheme to provide emissions reduction projects resulting in "certified emission reduction" (CER) credits, each equivalent to one tonne of carbon dioxide, which can be counted towards meeting Kyoto Protocol targets. It allows a country with an emission reduction or emission limitation commitment under the Kyoto Protocol to implement an emission reduction project in developing countries. The intention of the CDM is to stimulate sustainable development and emission reductions while providing developed countries with some flexibility in how they achieve their emission reduction targets (Leamon et al. 2013).

Two commitment periods are covered under the Kyoto Protocol:

- *Kyoto 1*: the first commitment period started in 2008 and ended in 2012. The participant industrialized countries agreed to reduce their GHG emissions in this period of time by an average of 5.2% with respect to the 1990 emissions levels. Switzerland made the same formal commitment as the European Union: a reduction in GHG emissions by an average of 8% between 2008 and 2012.
- *Kyoto 2*: the second commitment period, known as the Doha Amendment to the Kyoto Protocol, started in 2013 and ended in 2020, to bridge the gap between the end of Kyoto 1 and the start of a new global climate agreement, the Paris Agreement, in 2020. The following countries agreed to this further commitment period: Australia, the EU, Croatia, Iceland, Liechtenstein, Monaco, Norway and Switzerland.

In large part, the text of the Kyoto Protocol takes up the same terminology of the UNFCCC of 1992 and does not offer mayor novelties for CCUS processes neither explicit mention of CCU. The only exception is provided in art. 2 par. 1 sec. a subsec. iv of the Protocol (*Kyoto Protocol* 1997), which names for the first time "carbon dioxide sequestration technologies": "Each party [...] shall [...] implement and/or further elaborate policies and measures in accordance with its national circumstances, such as [...] research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies".

Moreover, for what concerns CCS, the decision by the meetings of the UNFCCC Parties in Durban, South Africa, in 2011, to accept CCS as clean development mechanism (CDM) project activities was the culmination of many years of international negotiation (UNFCCC 2011).

The Paris Agreement of 2015

Negotiations were held in the framework of the yearly UNFCCC Conferences on measures to be taken after the end of Kyoto 2. At the 19th Conference of the Parties (COP19) in 2013, the UNFCCC created a mechanism for Intended Nationally Determined Contributions (INDCs) to be submitted in the run up to the 21st session of the Conference of the Parties in Paris (COP21) in 2015. INDCs identify the post-2020 voluntary national climate targets, including mitigation and adaptation, which countries committed to and which will become a binding Nationally Determined Contributions (NDC) when a country ratifies the Paris Agreement.

Negotiations between the States Parties eventually resulted in the 2015 adoption of the Paris Agreement, which is a separate, legally binding instrument under the UNFCCC rather than an amendment of the Kyoto Protocol. As of March 2019, 195 UNFCCC members have signed the Paris Agreement, and 185 have become party to it.

The aim of the Paris Agreement is to limit average global warming to considerably less than 2 degrees Celsius compared to the pre-industrial era while aiming for a maximum temperature increase of 1.5 degrees Celsius. It also aims to channel state and private financial flows into low-GHG development and improving the capacity for adaptation to the changing climate. Furthermore, the agreement imposes a legally binding obligation on all states to submit and explain a nationally determined contribution every five years and largely eliminates the previous strict distinction between industrialized and developing countries. Compliance with the reduction targets, however, is not legally binding and the agreement does not contain a sanction mechanism in the event that a country fails to achieve the objectives it has communicated.

Art. 4 par. 1 of the Paris Agreement (*Paris Agreement* 2015) specifies the objectives to be achieved in stages: in order to obtain a GHG ceiling as soon as possible, it is necessary to reduce emissions quickly; thereafter, further reductions will have to be made, in accordance with the best available scientific data, with a goal of achieving a balance between anthropogenic emissions by sources and anthropogenic removals by GHG sinks during the second half of the century, i.e. from 2050. This second period invites the production of negative emissions in order to contain the effects of global warming below 2°C compared to preindustrial levels. Therefore, the Paris Agreement explicitly recognizes the role which can be played by CCS and by some CCU technologies (such as the valorization of CO_2 in construction materials) which fall into the category of "negative emissions" technologies.

5.1.2 THE EUROPEAN CONTEXT

While Switzerland itself is not part of the European Union (EU), it nevertheless benefits of a close relationship with the EU, based on a set of bilateral agreements: around 20 main agreements and some 100 secondary agreements have been concluded in several stages (Federal Department of Foreign Affairs 2016). This relationship has marked the efforts of Switzerland for the harmonization of its legislative corpus with the one of the EU in many policy areas of mutual cooperation, meaning that a significant part of Swiss legislation in these areas is often modeled after the EU existing legislation[11]. Therefore, it is important to examine the existing EU regulations of CCUS for a future Swiss regulatory process in this sector would also likely require similar forms of harmonization.

The EU climate change mitigation policy (including CCUS) is largely inspired by the international climate agreements (the UNFCCC of 1992, Kyoto 1, Kyoto 2, and more recently the Paris Agreement) and it has been drafted largely as a consequence of the engagements taken by the EU in those occasions. The "2030 climate and energy framework", a main instrument of the European Commission climate policy, adopted by EU leaders in October 2014 and revised in 2018, sets three key targets for the year 2030 (*Conclusions EUCO 169/14* 2014):

- At least 40% cuts in greenhouse gas emissions (from 1990 levels)
- At least 27% share of renewable energy to be consumed in the EU
- At least 27% improvement in energy efficiency

Various legislative measures have been adopted by the EU and its 28 Member States to implement the GHG emission reduction targets reported as an INDC to the UNFCCC (*INDC of the EU* 2015) on 06.03.2015. Some among them explicitly cite the capture of carbon dioxide.

EU Directives

In the last years, a certain number of Directives of the European Parliament and the European Council have been enacted to implement the goals of the EU climate policy, especially focusing on renewable energy targets and quality of fuels. Here we examine the Directives which contain provisions to regulate CCUS processes.

- Directive 2009/30/EC of 23 April 2009, or "2009 Fuel Quality Directive", amending Directive 98/70/EC of 13 October 1998 or

[11] *For instance, Swiss CO_2 emission performance standards for automobiles are shaped on the analogous EU standards (*CO_2 Ordinance *2012).*

"1998 Fuel Quality Directive", provides an indicative target of 2% GHG emissions reduction per unit of energy from fuel or energy supplied over the whole life cycle of the fuel or energy carrier, to be achieved by 31 December 2020 through different methods, one of which being CCS technologies (see art. 2 par. b sec. ii *Directive 2009/30/EC* 2009). This Directive is noticeable since opens the door to CCS related exclusively to compensate for indirect GHG emissions from the transportation sector, according to the approach of the "carbon offset". Moreover, given the current state of the art of CCS technologies, in which transportation emissions cannot be captured directly at their source, this Directive implicitly seems to refer only to DACCS technologies.

- Directive 2009/31/EC of 23 April 2009, or "CCS Directive", provides a legal framework for the geological storage of CO_2 in a way which is "safe for the environment". This directive amends Directive 2001/80/EC, or "Large Combustion Plant (LCP) Directive", to provide that Member States shall ensure that the operators of combustion plants with a power of 300 MW or more, reserve sufficient space for the equipment required for capturing and compressing CO_2. Its objective is to ensure that there is no significant risk of CO_2 leakage or damage to public health or the environment and to prevent any deleterious effect on safety transport network or storage sites. The CCS Directive also amends Directive 2000/60/EC, or "Water Framework Directive", in order to allow for injection of CO_2 into saline aquifers for the purposes of geological storage according to the provisions of EU legislation on the protection of groundwater against pollution and deterioration.

  The CCS Directive contains additional provisions about technical aspects related to CO_2 capture and transport. However, these aspects are mainly dealt with in the two following directives: (i) Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011, or "Environmental Impact Assessment (EIA)

Directive"[12], contains provisions for the conduct of environmental impact assessment of CCS projects; (ii) Directive 2010/75/EU, or "Industrial Emissions Directive", devotes in particular its art. 36 to the storage of carbon dioxide. Member States must ensure that operators of combustion plants with an electrical capacity greater than 300 MW, after the entry into force of Directive 2009/31/EC, evaluate the feasibility of capturing and storing carbon dioxide (par. 1).

- Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015, or "ILUC (Indirect Land Use Change) Directive", adds a new Annex IX to Directive 2009/28/EC on the promotion of the use of energy produced from renewable sources, or "Renewable Energy Directive". It includes, under certain conditions, the capture and use of CO_2 for transport purpose; in particular, the energy source must be renewable.

Piguet *et al.* have analyzed in detail the technical implications of the ILUC Directive and its origins (Piguet et al. 2017). They mention in particular a report of the European Economic and Social Committee (EESC) which advocates for a sharp rise in renewable energy production and in energy storage and envisages a large array of different technological options to reach this goal. This report notably singles out "methanised hydrogen", a synthetic fuel (methane) produced from the combination of CO_2 and hydrogen. Consequently, the EESC underlines that methanised hydrogen has by far the greatest energy storage potential in current gas infrastructures (for long periods) and can also form hydrocarbons with multiple applications (notably as substitutes for fossil resources in plastics), see EESC 2015. In the current literature, the term "methanised hydrogen" is usually replaced by other synonyms, including "CO_2 methanation" or "power-to-gas" (which defines the process) and "renewable power methane" (which defines the final product). In addition to methane, the combination of CO_2 and hydrogen can also provide liquid fuels such

[12] *As amended by Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014.*

as methanol. The term "CO_2 hydrogenation" is usually used to denote the industrial process, whereas the term "CO_2-fuels" is used to denote the final products.

In the perspective of the legislative process related to CCU technologies, it is important to get a comprehensive evaluation of the CO_2 savings by unit of energy during the lifetime of the CCU-based products, compared with the equivalent CO_2 emissions from the conventional fossil fuels or fossil-based products that CCU-based products are meant to substitute. For instance, according to Meylan et al. (F. Meylan et al. 2017), the CO_2-eq emissions of natural gas (including indirect emissions caused by extraction) amount to 66.1 g CO_2-eq/MJ. This amount can serve as a benchmark when comparing estimates of CO_2 savings from different kinds of CO_2 methanation. Emissions from CO_2 methanation (including the first use of carbon as well as the combustion of renewable power methane) range from 7.1 to 46.1 g CO_2 -eq/MJ, depending on the sources of CO_2 and electricity. CO_2-fuels can be of interest, from the point of view of decreasing carbon emissions, even when the CO_2 is issued from the combustion of fossil resources, provided that hydrogen from renewable electricity is used.

These very recent EU regulations on CCUS seem to denote a complementary approach between carbon dioxide recycling and CO_2 geological sequestration. According to this approach, "renewable electricity production and renewable power methane could be substituted for fossil energy (thereby limiting fossil energy exploitation and combustion), while geological storage would limit CO_2 emissions when it is not yet possible to cut drastically the use of fossil energy" (Piguet et al. 2017). For example, we have seen above that Directive 2009/30/EC deals with CCS explicitly in the optics of offsetting carbon emissions from transportation fuels. Whether this will remain a main concern in the future, it will also depend upon the pace of deployment of electric vehicles and their replacement of internal combustion engine vehicles.

Directive 2015/1513 lists 20 feedstocks dedicated to the production of advanced renewable fuels, four of which are characterized by CO_2 valorization:

- "Algae if cultivated on land in ponds or photobioreactors"[13]. The growth of certain microalgae species is stimulated by the injection of concentrated carbon dioxide streams. The Directive does not specify the origin of the CO_2 (biomass or fossil?) used for the growth of the algae.
- "Bacteria, if the energy source [which is used to power the process] is renewable". As in the previous case, this item does not specify the origin of the CO_2 employed to stimulate the growth of the bacteria. "Cyanobacteria, which are prokaryotic microalgae cultivated in open ponds and photobioreactors, are probably the species designated by this provision" (Piguet et al. 2017)
- "Renewable liquid and gaseous transport fuels of non-biological origin". This provision fits the definition of hydrogen as a transport fuel, but could also include the CO_2-fuels originated from capture and hydrogenation of carbon dioxide.
- "CCU for transport purposes". This item addresses the development of CO_2 hydrogenation as a substitute to fossil fuels.

The last two feedstocks will also be helpful in order to tackle the electricity storage challenge (F. D. Meylan et al. 2016).

- The Directive 2003/87/EC ("2003 ETS Directive") of 13 October 2003, establishing a scheme for GHG emission allowance trading within the EU, namely the EU Emission Trading System (EU ETS). The main long-term incentive arising from this Directive for CCS, for

[13] *The term "algae" refers to a great diversity of organisms which convert sunlight into energy using photosynthesis, like plants. The key to algae's potential as a renewable fuel source lies in increasing algal biomass productivity per acre. Some researchers say algae could be 10 or even 100 times more productive than traditional bioenergy feedstocks. Achieving these high productivities in real-world systems is a key challenge to realizing the promise of sustainable and affordable algal biofuels. Once harvested, algae can be readily processed into the raw material to make fuels for cars, trucks, trains, and planes.*

new renewable energy technologies and for breakthrough innovation in low-carbon technologies and processes, including environmentally safe CCU, is the carbon price signal it creates and the fact that allowances will not need to be surrendered for carbon dioxide emissions which are avoided or permanently stored.

- The Directive 2018/410 ("2018 ETS Directive"), amending the 2003 ETS Directive to enhance cost-effective emission reductions and low-carbon investments, establishes an allowances fund to provide guaranteed rewards for deployment of CCS or CCU facilities, new renewable energy technologies and industrial innovation in low-carbon technologies and processes in the EU for CO_2 stored or avoided on a sufficient scale, provided an agreement on knowledge sharing is in place.

The EU ETS is discussed in more detail below.

The EU ETS and the carbon levies

The main instrument of climate policy in the EU remains the EU Emission Trading System (EU ETS), which was launched in 2005. It is a "cap and trade" system in which a maximum (cap) is set on the total amount of GHG that can be emitted by all installations covered by the system, which are mainly constituted by the power sector and large industrial installations in the EU (*Directive 2003/87/EC* 2003). This cap is not fixed, since its goal is to bring down GHG emissions, not to keep them constant. Instead, in the period 2013-2020, this cap is reduced every year by 1.74%: in this manner, in 2020 emissions from power stations and other large fixed installations should decrease 21% with respect to the amount emitted in 2005[14] (European Commission 2016). "Allowances" for emissions[15], in a number equal to the value of the cap, are then either auctioned off or allocated for free to these installations, and can

[14] *A separate cap is set for the aviation sector, which for the whole 2013-2020 period is 5% below the average annual level of GHG emissions in the years 2004-2006 (European Commission 2016).*

[15] *1 allowance represents 1 tonne of CO2 or CO2-equivalent emissions.*

subsequently be traded between the installations themselves according to their needs. The operators of the installations must monitor and report their GHG emissions, ensuring they surrender enough allowances to the authorities to cover their emissions. At the end of the year, if the reported emissions from a given installation exceeded what its surrendered allowances permitted, a penalty[16] must be paid by the operator of the installation. Conversely, if an installation has performed well at reducing its emissions, it can sell its leftover credits or conserve them for future needs. This should allow the system to find the most cost-effective ways of reducing emissions by putting a price on GHG emissions with a market-based mechanism (Carbon Market Watch 2014).

However, it must be noticed that the EU ETS market suffers from an excessive number of free allowances. In fact, while about 40% of allowances are being auctioned and power generators have to buy all of their allowances (with exceptions in some member states like Poland, Bulgaria, Hungary, Lithuania, etc.), free allocations still prevail in other sectors such as the manufacturing industry and the aviation sector. As a consequence of the generous distribution of free emissions allowances, prices for carbon permits were never as high as envisaged, thereby reducing the effectiveness of the ETS (Carbon Market Watch 2014).

While emissions trading has the potential to cover many economic sectors and GHGs, the EU ETS focuses on emissions which can be measured, reported and verified to a high degree of accuracy. Therefore, the focus is on energy intensive installations in power generation and manufacturing industry sectors, as well as operators of flights to and from EU Member States, Iceland, Liechtenstein and Norway[17]. Furthermore, only three GHGs - carbon dioxide (CO_2), nitrous oxide (N_2O) and perfluorocarbons (PFCs) - are covered by the System (European Commission 2016), since

[16] *In 2013, the penalty amounted to EUR 100 per each tonne of carbon dioxide equivalent. It rises every year in line with the European consumer price index (European Commission 2016).*

[17] *As of September 2016, these are the only states outside the EU which have joined the trading system.*

the emissions of other GHGs are either negligible or too difficult to measure and report.

CCS technologies are explicitly named in the legal foundations of the EU ETS through later amendments of the original ETS Directive 2003/87/EC ("2003 ETS Directive"), namely Directive 2009/29/EC of 23 April 2009 ("2009 ETS Directive") and Directive (EU) 2018/410 of 14 March 2018 ("2018 ETS Directive"). In particular, the 2009 ETS Directive states that "the main long-term incentive for the capture and storage of CO_2 [...] is that allowances will not need to be surrendered for CO_2 emissions which are permanently stored or avoided[18]. In addition, to accelerate the demonstration of the first commercial facilities and of innovative renewable energy technologies, allowances should be set aside from the new entrants reserve to provide a guaranteed reward for the first such facilities in the Union for tonnes of CO_2 stored or avoided on a sufficient scale [...]. The additional financing should apply to projects of sufficient scale, which are innovative in nature and which are significantly co-financed by the operator covering, in principle, more than half of the relevant investment cost, and taking into account the viability of the project" and that "from 2013 onwards, the environmentally safe capture, transport and geological storage of CO_2 should be covered by the [European] Community scheme in a harmonized manner"[19]. This Directive also introduces a possible source of financial aid for CCS technologies, by stating that "at least 50% of the revenues generated from the auctioning of allowances" should be used, among others, for CCS measures such as afforestation and forestry sequestration, as well as "the environmentally safe capture and geological storage of CO_2, in particular

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[18] *In other words, the installations first receive a certain number of allowances based on the amount of GHG that can be emitted, then it gets to keep a number of allowances (instead of using them) in respect of the amount of CO_2 which has been captured and stored instead of emitted. These allowances then can be traded, making CCS potentially interesting from a financial perspective.*

[19] *Art. 45 clarifies that this 'harmonization' would probably require further amendments of the original EU ETS Directive 2003/87/EC and affect rules such as the definition of 'new entrant', the auctioning and allocation of allowances, the establishment of the criteria and modalities applicable to the selection of certain demonstration projects, etc. (*Directive 2009/29/EC *2009).*

from solid fossil fuel power stations and a range of industrial sectors and sub-sectors, including in third countries" (*Directive 2009/29/EC* 2009). On the other hand, Directive (EU) 2018/410 introduces the possibility to make a certain amount of allowances available to support new projects not just in the sector of CCS, but also in CCU.

Another important point concerning CCUS incentives, as reported above, is the EU plans to reserve a certain number of allowances for new entrants: more precisely, the "New Entrants Reserve" (NER) constitutes a special-purpose, EU-wide pool of emission allowances set aside for new installations and installations that increase capacity, which are covered by the scope of the EU ETS Directive, and which are eligible for additional free allocation in phase 3 of the European Union Emissions Trading System (EU ETS). According to art. 3 let. h of the Directive 2009/29/EC, a new entrant can be either one of the following: (1) new installations, receiving a GHG permit after 30 June 2011, or (2) significant capacity extensions at existing installations after 30 June 2011 (*Directive 2009/29/EC* 2009).

The EU ETS currently covers just around 45% of the EU's GHG emissions (European Commission 2016). Hence, in addition to this system, carbon taxes levied on CO_2 emissions have been individually put in place in 14 European countries in order to cover non-ETS emissions from motor fuels, the residential sector and smaller industrial installations (which account for more than half of total CO_2 emissions).

Carbon pricing initiatives, i.e. both carbon taxes and emission trading systems, have been developing around the world in the last decades. A global map of the state of implementation of these initiatives as of 2018 is shown in Fig. 5.1.

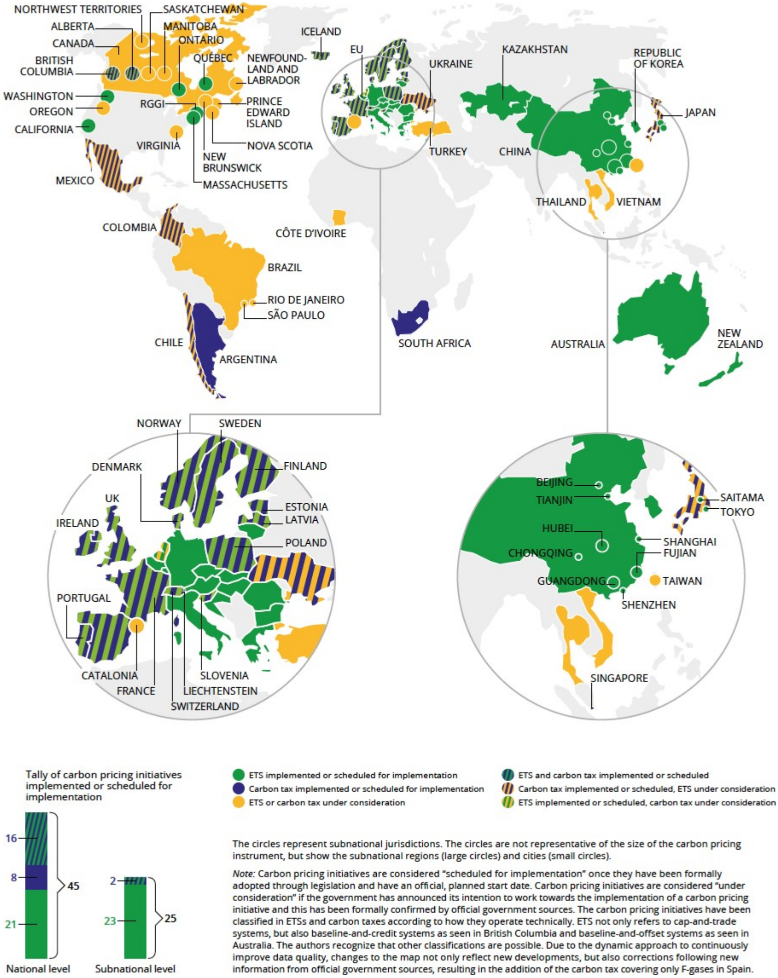

Figure 5.1: Summary map of regional, national and subnational carbon pricing initiatives (both ETS and carbon tax) implemented, scheduled for implementation and under consideration worldwide as of 2018.
Switzerland is one of the few countries having a mixed ETS-carbon levy system.
Source: World Bank 2018.

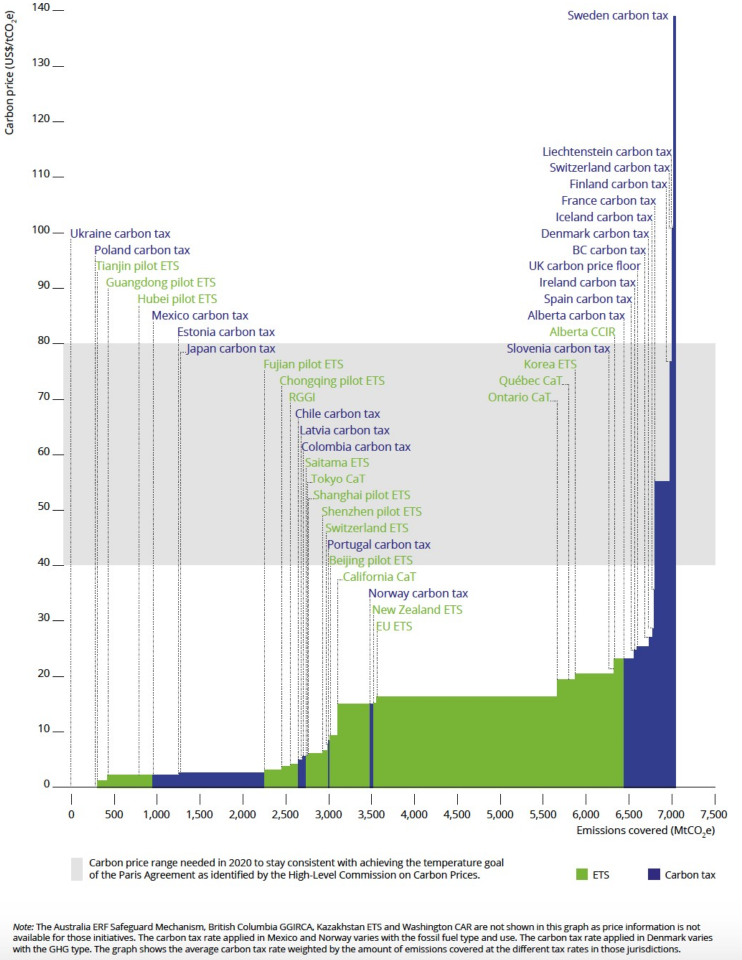

Figure 5.2: Carbon price and emissions coverage of implemented carbon pricing initiatives worldwide as of 2018.

It shows that the carbon price settled in the frame of the Swiss ETS is much lower than the one settled by the CO_2 levy. It also shows that the vast majority of ETS prices and carbon taxes in the world are still well below the carbon price range that would be needed by 2020 to stay consistent with achieving the temperature goal of the Paris Agreement of "well below 2°C". Source: World Bank 2018.

Compared to a situation without a price on CO_2, the introduction of a carbon tax and/or an ETS increases the cost-effectiveness and application scales in the market of CCUS technologies since the additional cost caused by a high carbon tax could be avoided when the carbon dioxide is captured instead of released in the atmosphere. In this sense, the introduction of a higher carbon price through a higher ETS pricing or a higher carbon tax should stimulate the deployment of CCUS application and then lead to a decrease of CO_2 emissions in the power sector. Fig. 5.2 shows how the ideal value of the carbon price which would be needed to achieve the Paris Agreement goals is still much higher than the actual price of CO_2 emissions in the various world countries which have adopted carbon pricing mechanisms.

5.1.3 THE SWISS CONTEXT

Compared to the international and the European context, the Swiss legislation about CCUS is still practically non-existent. Nevertheless, there are a number of pieces of legislation, either proposed or approved, related to GHG emissions reduction efforts which can be connected with possible development of CCUS technologies.

Fig. 5.3 provides an overview of the most relevant cross-sectoral climate policies and measures in Switzerland. These measures are mainly contained in the centerpiece of the Swiss climate legislation, the CO_2 Act, first enacted in 1999 and then updated in 2011, whose main goals were to meet the commitments of the Confederation under the UNFCCC. Specifically, the 1999 CO_2 Act (*CO_2 Act* 1999) and the 2011 CO_2 Act (*CO_2 Act* 2011) were enacted to provide a legal basis for the implementation of the first (2008-2012) and the second (2013-2020) commitment periods under the Kyoto Protocol (*Kyoto 1* and *Kyoto 2*, see section 5.1.1), respectively. The Federal Council has then detailed certain instruments and provisions of the two CO_2 Acts in two Ordinances, in 2007 and 2012 (*CO_2 Ordinance* 2007; *CO_2 Ordinance* 2012).

Name of policy or measure [a]	Green-house gas(es) affected	Objective and/or activity affected	Type of instrument	Status of imple-mentation	Brief description	Start year of imple-mentation	Imple-menting entity or entities	Estimate of mitigation impact (not cumulative, in kt CO_2eq) 2020
First CO_2 Act (1999) *	CO_2	Average reduction of CO_2 emissions from fossil fuel use by 10 per cent over the years 2008–2012 (relative to 1990).	Regulatory	Expired (replaced by second CO_2 Act)	First legal basis of Switzerland's climate policy including the implementation of the first commitment period of the Kyoto Protocol.	2000	FOEN	IE [b]
Second CO_2 Act (2011) *	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3	Reduction of all greenhouse gas emissions by 20 per cent by 2020 (relative to 1990).	Regulatory	Imple-mented	Current legal basis of Switzer-land's climate policy including the implementation of the second commitment period of the Kyoto Protocol and containing provisions covering mitigation as well as adaptation.	2013	FOEN	IE [b]
Third CO_2 Act (2021)	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3	Decrease of total greenhouse gas emissions (relative to 1990) by (i) 50 per cent by 2030 (at least 30 per cent domestic and at most 20 per cent abroad) and (ii) 35 per cent in the mean over the years 2021–2030 (at least 25 per cent domestic and at most 10 per cent abroad).	Regulatory	Planned	Update of the CO_2 Act providing the legal basis of Switzerland's climate policy consistent with the Paris Agreement. While mostly covering the same policies and measures as the second CO_2 Act, the third CO_2 Act foresees a strengthening of the policies and measures in order to reach the more ambitious national and international targets.	2021	FOEN	IE [b]
CO_2 levy on heating and process fuels *	CO_2	Promote energy efficiency, less CO_2 intensive energy sources and reduced use of fossil heating and process fuels.	Economic, fiscal	Imple-mented (strength-ening planned)	Surcharge on fossil heating and process fuels. Two thirds of the revenues are redistributed to households and businesses, up to one third goes into the national buildings refurbishment programme and – to a small extent – to a technology fund granting loan guarantees for the development of new low-emission technologies.	2008	FOEN	1'600 [c]
Emissions trading scheme *	CO_2, N_2O, PFCs	Reducing CO_2 emissions of emission-intensive industries using market-based mechanism.	Economic	Imple-mented (strength-ening planned)	Emissions trading scheme based on the cap and trade principle, enabling the cost-effective achievement of climate-protection targets. Large greenhouse gas-intensive companies are required to participate, medium-sized companies may voluntarily participate. Companies included in the emissions trading scheme are exempt from the CO_2 levy on heating and process fuels.	2008	FOEN	800
Negotiated reduction commitments (for exemption from the CO_2 levy) *	CO_2, N_2O, PFCs	Emission reduction targets agreed with companies exempt from the CO_2 levy on heating and process fuels.	Regulatory	Imple-mented (strength-ening planned)	Binding agreements with eligible small and medium-sized companies. Emission reduction targets take the technological potential and economic viability of measures into account. Targets are calculated from the starting point along a simplified or individual linear reduction course to the endpoint in the year 2020. Alternatively, economically viable measures (measures target) can be determined.	2008	FOEN, SFOE	400

[a] Policies and measures marked with an asterisk (*) are included in the 'with measures' projection.

[b] The first, second and third CO_2 Acts are the legal framework for various measures. While the expected mitigation impacts of individual policies and measures are presented along with these policies and measures, the total mitigation impacts of the CO_2 Acts correspond to the objectives indicated in the third column.

[c] For the purposes of estimating the mitigation impact, the CO_2 levy on heating and process fuels was fixed at 36 Swiss francs per tonne of CO_2 for the period 2010–2015. For 2016–2020, it was assumed that the CO_2 levy on heating and process fuels would be raised to 72 Swiss francs per tonne of CO_2.

IE, included elsewhere
FOEN, Swiss Federal Office for the Environment; SFOE, Swiss Federal Office of Energy

Figure 5.3: Overview of the most relevant cross-sectoral climate policies and measures in Switzerland. Source: FOEN 2018a.

As of 1 January 2014:
- Increase to 60 Swiss francs per tonne of CO_2 if the CO_2 emissions from heating and process fuels in 2012 exceed 79 per cent of 1990 emissions.

⇨ The rate of the CO_2 levy was increased to 60 Swiss francs per tonne of CO_2.

As of 1 January 2016:
- Increase to 72 Swiss francs per tonne of CO_2 if the CO_2 emissions from heating and process fuels in 2014 exceed 76 per cent of 1990 emissions;
- Increase to 84 Swiss francs per tonne of CO_2 if the CO_2 emissions from heating and process fuels in 2014 exceed 78 per cent of 1990 emissions.

⇨ The rate of the CO_2 levy was increased to 84 Swiss francs per tonne of CO_2.

As of 1 January 2018:
- Increase to 96 Swiss francs per tonne of CO_2 if the CO_2 emissions from heating and process fuels in 2016 exceed 73 per cent of 1990 emissions;
- Increase to 120 Swiss francs per tonne of CO_2 if the CO_2 emissions from heating and process fuels in 2016 exceed 76 per cent of 1990 emissions.

⇨ The rate of the CO_2 levy was increased to 96 Swiss francs per tonne of CO_2.

Figure 5.4: Intermediate targets set out in art. 94 of the CO_2 Ordinance to the second CO_2 Act.
These targets include corresponding increases of the CO_2 levy in case of non-compliance with the intermediate targets (the intermediate targets set out in art. 3 of the CO_2 Ordinance to the first CO_2 Act are not shown here). The attainment of the targets is evaluated based on the CO_2 statistics which is annually published at the beginning of July and which contains CO_2 emissions from heating and process fuels from the previous year. Source: FOEN 2018a.

The CO_2 Act and its instruments

The 2011 CO_2 Act, currently[20] in force, contains some instruments already outlined in the 1999 CO_2 Act, included a CO_2 levy for heating, industrial process, and transportation fuels, as well as a Swiss emissions trading system (ETS) that included Kyoto Protocol flexibility mechanisms[21].

The Swiss CO_2 levy, which was introduced only on 1 January 2008 since other measures to reach the CO_2 emission reduction goals had failed[22], is a levy on thermal fuels (for heating and industrial processes), whereas motor fuels are exempt from the levy but their emissions have to be partially compensated. By increasing the price of fossil heating and process fuels, the CO_2 levy sets an incentive to use fossil fuels more efficiently, to invest in low carbon technologies, and to switch to low-

[20] *I.e., as of 2019.*

[21] *This means that the system offers flexibility to businesses covered by the ETS as they have the choice between reducing emissions and purchasing emission allowances from other companies depending on the price of carbon. This promotes the realization of cheap GHG emissions reductions while the costly reduction measures can be postponed.*

[22] *The CO_2 levy is designed as a steering tax, that is, a tax which aims to change the behavior of the tax payer, as defined by lawmakers, and not particularly to increase tax revenue. Hence, of its proceeds, about two-thirds are redistributed to households and firms, while the remaining third is used to finance a building renovation programme and a technology fund (see chapter 6 of* CO_2 Act *2011 and Ott and Weber 2018).*

carbon or carbon-free energy sources. The initial rate of the CO_2 levy when introduced in January 2008 was 12 Swiss francs per tonne of CO_2. The 2012 CO_2 Ordinance foresees an automatic increase of the rate to a maximum of 120 Swiss francs per tonne of CO_2 in case CO_2 emissions from heating and process fuels in 2016 exceed 76% of 1990 emissions (FOEN 2018a), as shown in Fig. 5.4.

The Swiss ETS, analogously to the EU ETS, is based on the trade of *emission allowances*, which are tradable rights to emit GHGs allocated by the Confederation or by states with emissions trading schemes recognized by the Federal Council, and *emission reduction certificates*, which are internationally recognized tradable documents attesting to reductions in emissions achieved abroad. The Swiss ETS was also introduced, like the CO_2 levy, on 1 January 2008 as an alternative option for complying with the national CO_2 levy. In other words, firms covered by the levy have two choices: (1) pay the CO_2 levy, or (2) voluntarily set a verified absolute emissions target and associated allowance allocation and participate in the Swiss ETS, which exempt them from the levy. In essence, the CO_2 levy functions as a hard price ceiling for covered entities, and the option for ETS participation allows firms to potentially pay a lower rate for emissions reductions than this ceiling price since, as Fig. 5.2 shows, the carbon price settled in the frame of the Swiss ETS is much lower than the carbon price settled by the CO_2 levy or carbon tax. The revisions to the Swiss ETS enacted with the 2011 CO_2 Act have increased its similarity to the EU ETS, thereby providing comparable market conditions for Swiss and EU industries and improving the prospect of linking with the EU ETS (Environmental Defense Fund et al. 2015).

Art. 7 of the CO_2 Act also introduces the possibility of issuing *attestations for domestic emission reductions* for “reductions in GHG emissions achieved voluntarily in Switzerland” and specifies that the Federal Council may consider these documents to be equivalent to the emission allowances or emission reduction certificates previously discussed. The CO_2 Ordinance provides the guidelines for issuing such attestations (art. 5 to 11) and states that these documents can be surrendered to the

Confederation in order to meet a *compensation obligation*, i.e. an obligation to compensate for the GHG emissions caused (see e.g. section 2 and section 3 of the CO_2 Act and art. 83 and 90 of the CO_2 Ordinance).

In certain economic sectors, some companies can be refunded of the CO_2 levy "provided that they undertake to the Confederation to reduce greenhouse gas emissions by a specific amount by 2020 (*reduction obligation*) and to submit an annual report on their efforts" (art. 31 of the CO_2 Act). In conclusion, three types of companies are exempted from the CO_2 levy: ETS companies, power plant operators and companies with reduction obligations (as summarized by art. 96 par. 2 of the CO_2 Ordinance).

The CO_2 Act is being revised again in 2019 in order to extend this instrument of the Confederation climate policy beyond 2020 and until the year 2030. The "Dispatch on the complete revision of the CO_2 Act for the period after 2020" by the Federal Council of 1 December 2017 underlines the necessity of this revision due to the ratification of the Paris Agreement by the Federal Council, by which the Council has accepted the goal to decrease by 50% the GHG emissions relative to the 1990 emissions level by 2030. It also acknowledges that if CO_2 emissions will have to be stabilized at zero net in the second half of this century so that GHG emissions are balanced by corresponding negative emissions, we need to develop CCS technologies alongside reducing emissions (*Dispatch on the revision of the CO_2 Act* 2017).

Another important provision proposed by the Federal Council for the new version of the Act concerns the linkage between the Swiss ETS and the EU ETS, in order to maximize its effectiveness, since the efficiency of an ETS increases when the number of installations covered by the system is bigger. With the coupling between the two systems, there will be the mutual recognition of Swiss and EU emission rights and installations required to participate in the ETS of Switzerland or the EU may use emission allowances for both systems to cover their emissions. This will also lead to an alignment of the prices of the emission rights between

Switzerland and EU and, for the Swiss companies, conditions of competition similar to those of their European competitors (*Dispatch on the revision of the CO_2 Act* 2017).

Indeed, the CO_2 Act as a whole has not produced a decrease in GHG emissions by the amount which was expected. It is true that between 2008 and 2015, the cumulative reduction amounted to 4.1 to 6.9 million tonnes of CO_2-eq and that in 2015, emissions were 0.8 to 1.3 million tonnes of CO_2-eq lower than those in the baseline scenario that did not include the carbon tax (Müller and Schoch 2017). However, according to the available data, it looks like the overall target of a 20% reduction in carbon dioxide emissions by 2020 compared to 1990 levels will likely not be attained. More in detail, while the target for the industry of a 15% reduction has already been reached years ahead, the target for the transportation sector of a 10% reduction should be clearly missed. It has also been noticed that GHG emission reductions are higher when the amount of the tax is raised and that significant reduction potential has not yet been exhausted due to the relatively low tax base in the first years after the introduction of the levy in 2008 (*Dispatch on the revision of the CO_2 Act* 2017). Therefore, the increase of the CO_2 levy on fossil fuels proposed by the Federal Council would both help reaching the emissions reduction targets and be a good starting point for CCUS development in Switzerland.

Prospects for CCUS under the current CO_2 Act

In its current formulation, the 2011 CO_2 Act already presents a certain number of provisions which could also be applied to CCUS:

- First of all, the formulation of the aim of the Act, which is "to reduce greenhouse gas emissions and in particular CO_2 emissions that are attributable to the use of fossil fuels (thermal and motor fuels) as energy sources with the aim of contributing to limiting the global rise in temperature to less than 2 degrees Celsius" (art. 1 par. 1), allows to take into account CCUS technologies, when applicable to flue gas at the exit of concentrated point sources, by retrofitting installations at a site with CCU or CCS. At first sight, DAC seems to be the only carbon capture method to which this article does not explicitly apply, since DAC does not intervene on direct GHG emissions, but rather capture molecules of carbon dioxide in the atmosphere regardless of their origin, natural or anthropogenic. However, other articles such as those in section 4.2 of the Act ("Compensation in the case of Fossil-Fuel Thermal Power Plants") and in chapter 7 of the 2012 CO_2 Ordinance introduce the concept of "compensation" of GHG emissions and hence expand the scope of the Act to a reduction of *net* GHG emissions, clarifying the somehow ambiguous formulation of art. 1 of the Act and allowing to consider DAC as a method to achieve the targets of the Act.

- However, one should notice that there are *not* explicit mentions of CCUS in the whole Act and in the Ordinance, contrarily to other emissions reduction options such as energy efficiency or transition to renewable energy sources as for instance in art. 83 ("Permissible compensation measures") of the 2012 CO_2 Ordinance.
- Art. 4 par. 2 specifies that "measures that reduce greenhouse gas emissions in accordance with other legislation should also contribute to achieving the reduction target" and that "these measures include in particular those in the fields of environment and energy, agriculture, forestry and timber industry": as a matter of fact, a number of CCUS technologies fall into these categories. For instance, BECCS and BECCU are measures which can be included in the 'environment and energy' and 'agriculture' categories, afforestation is a measure in the 'forestry' category, and timber industry installations could expand their activities by recycling the carbon dioxide produced in the facilities' processes as a raw material for bio-products[23] (see e.g.

[23] *This is one example of the concept of "integrated biorefinery", that is, facilities that use biomass conversion processes and equipment to produce any combination of renewable fuels, power, heat, steam, and chemicals from biomass. They are analogous to today's petroleum refineries which produce multiple fuels and products from fossil petroleum.*

Kuparinen et al. 2019). This part of the Act fits particularly well the intrinsic cross-sectoral nature of CCUS.

- Another instrument regards partial compensation of CO_2 emissions both from fossil-fuel thermal power plants and from motor fuel use. Sec. 4.2 of the Act claims that fossil-fuel thermal power plants must compensate in full for the CO_2 emissions caused and that no more than 50% of the emissions may be compensated for through emission reduction certificates, meaning that at least 50% of the compensations must be achieved through emission reduction measures in Switzerland. Art. 83 of the Ordinance states that domestic emission-reduction projects and programmes self-implemented by the power plant operator are permissible to meet a compensation obligation. On the other hand, based on Sec. 4.3 of the Act, fossil fuel importers are bound to offset part (at most 40 per cent) of the carbon dioxide emissions from motor fuel use through investments in domestic emission reduction projects[24]. The offset is financed by a surcharge on imported fuels which shall not exceed 0.05 Swiss francs per liter of fuel. The Federal Council determined in art. 89 of the CO_2 Ordinance the share of CO_2 emissions from motor fuels to be offset by fuel importers as follows: 2% in 2014–2015; 5% in 2016–2017; 8% in 2018–2019; 10% in 2020. As before, art. 83 of the Ordinance states that self-implemented domestic emission-reduction projects and programmes are allowed to meet a compensation obligation.
- This provision is hence an opportunity for power plant operators and fossil fuel importers to select CCUS projects, for instance DACCS projects, to offset their emissions. DACCS projects are probably among the most suited measures for such compensations, since the amount of CO_2 which is captured and stored can be quantified with a

[24] *According to art. 86 par. 1 of the CO_2 Ordinance, "Persons or companies are subject to compensation obligations if: (a) they release motor fuels for consumption [. . .]; or (b) they convert fossil gases for combustion purposes to gases for use as motor fuels [. . .]". Small quantities of motor fuels released for consumption (resulting in emissions of less than 1000 tonnes CO_2 per year) are exempted from the compensation obligation, according to art. 87.*

good level of precision, provided that the electricity source for the project is known and that there are not leakages of the carbon dioxide stored underground, whereas in general other CCUS projects rely on more complex life cycle assessments which makes more complicated to quantify the amount of CO_2 emissions which have been actually compensated.

- In general, the requirement in art. 5 par. 1 sec. c of the CO_2 Ordinance that emission reductions must be "verifiable and quantifiable" seems to favor CCS over CCU projects, since lifecycle CO_2 emissions from CCU processes are more difficult to assess than those from CCS processes. In fact, CCU processes depends on a greater number of variables with large uncertainties, for example about the residence time of CO_2 in the final products (cf. Table B.1).

Summary of the Swiss PAP

The main provisions which can be used to identify the PAP of a CCUS public policy can be found in *CO_2 Act* 2011, since CCUS techniques are possible measures to reduce carbon dioxide emissions according e.g. to the guidelines of art. 4 *CO_2 Act* 2011.

For sake of simplicity, we will refer here only to federal legislation and ordinances and not to international agreements, though the latter have certainly played a fundamental role in shaping the climate legislation at the national level.

The scheme of the PAP is presented in Table 5.1. Such a scheme normally distinguishes between *substantial elements* and *institutional elements* of the PAP.

Substantial elements include:

Substantial elements	Concrete objectives	"Domestic GHG emissions must be reduced overall by 20 per cent as compared with 1990 levels, by 2020. The Federal Council may set sector-specific interim targets"(art. 3 par. 1 *CO_2 Act* 2011). "The Federal Council may increase the reduction target to 40 per cent in order to comply with international agreements" (art. 3 par. 2 *CO_2 Act* 2011).
	Evaluative elements	The Federal Council periodically evaluates the effectiveness of the measures under the CO_2 Act and the necessity of additional measures. In doing so, it also considers climate-relevant factors such as demographic, economic and traffic growth. It bases its assessment on statistical surveys and submits regular reports to the Federal Assembly (art. 40 *CO_2 Act* 2011). Moreover, the FOEN maintains the greenhouse gas inventory and, based on the inventory, calculates whether the reduction target under Article 3 of the CO_2 Act has been met (art. 131 *CO_2 Ordinance* 2012).
	Operational elements	(1) CO_2 levy on fossil thermal fuels, (2) Switzerland's Emission Trading Scheme (ETS), (3) partial compensation for emissions from motor fuels, (4) reduction of CO_2 emissions from new passenger cars, (5) obligation for fossil-fuel thermal power plants to compensate in full for the CO_2 emissions caused, (6) obligation for motor fuels producers to compensate between 5 and 40% of the CO_2 emissions that are attributable to the use of the motor fuels as energy source, (7) refund of the CO_2 levy for companies with an obligation to reduce GHG emissions; a systemof penalties is set up as well for (a) emissions that are neither covered by emission allowances nor, if permitted, by emission reduction certificates of the ETS, (b) exceedingthe emission reduction targets set for new passenger cars, (c) non-compliance by fossil-fuel thermal power plants or by motor fuels producers with the contractual obligation to compensate for the emissions caused (see *CO_2 Act* 2011). However, emission reduction certificates and attestations for domestic emission reductions cannot be issued for reductions achieved from projects of biological CO_2 sequestration and geological CCS (see *CO_2 Ordinance* 2012). Finally, it is established that emissions "shall be captured as fully and as close to the source as possible and shall be removed in such a way as to prevent excessive ambient air pollution levels" (art. 6 par. 1 *OAPC* 1985).

Institutional elements	Organisation, financial means and other resources	The FOEN is charged of the implementation of the CO_2 Ordinance. However, the SFOE shall implement the provisions relating to the reduction of CO_2 emissions from passenger cars, vans and light articulated vehicles. It is supported by the FEDRO (Federal Roads Office). The FCA (Federal Customs Administration) shall implement the provisions relating to the CO_2 levy. In consultation with the SFOE, the FOEN shall implement the provisions on attestations for domestic emission reductions and on the promotion of technologies for the reduction of GHG emissions. The SFOE and private organisations commissioned by the SFOE or the FOEN support the FOEN in implementing the provisions relating to commitments to reduce GHG emissions (from art. 130 *CO_2 Ordinance* 2012).
	Procedural elements	The procedural provisions of the mineral oil tax legislation, as well as additional provisions specifically contained in the 2012 CO_2 Ordinance, apply to the collection and refund of the CO_2 levy (see art. 33 *CO_2 Act* 2011 and chapter 8 of *CO_2 Ordinance* 2012). Moreover, the 2012 CO_2 Ordinance also details the procedures for the issuance of attestations for the operational elements (2), (3), (4), (5) and (6) listed above.

Table 5.1: The political-administrative programme (PAP) relative to a possible public policy of CCUS in Switzerland.

- *concrete objectives*, namely the specific goals which aim to describe the desired situation in a field of action once the public problem has been solved. In this respect the PPA of CCUS, derived from the broader PPA of the Swiss climate policy, is peculiar since the goal to reach is merely a short-term target of 20% or 40% in domestic GHG emissions reduction by 2020 compared with 1990 levels. While this goal can hardly be regarded as a solution to the issue of climate change, it is explained by the fact that the validity of the 2011 CO_2 Act is limited to the period up to the year 2020, after which it needs to be replaced by a new version of the Act. One can also note that art. 3 of the 2012 CO_2 Ordinance also specifies sectoral interim targets. They require the building sector, the industry sector to reduce their emissions by 22 per cent and 7 per cent, respectively, with respect to the 1990 levels, whereas the traffic sector is required to stabilize its emissions at the 1990 level, by the year 2015. However, since these targets are referred to the past, we do not consider them as being part of the current PAP;

- *evaluative elements*, namely the tools and instruments at disposition of the public authorities to collect different types of empirical data relating to the problematic issue (in this case, the increasing concentration of GHGs in the atmosphere and anthropogenic climate change) to be regulated by the PP. In this case, the main instrument to collect data to understand both the nature of the issue and the level of impact of the PP on its solution is the GHG Inventory, which is managed by the FOEN;
- *operational elements*, namely the intervention tools of the PPs for behavior change of the target groups. They are numerous: the CO_2 levy, the Swiss ETS, the obligation to partially compensate GHG emissions from motor fuels, the reduction of CO_2 emissions from new passenger cars (which could be done for instance by CO_2-fuels or by biofuels produced in combination with CCS), the obligation for fossil-fuel thermal power plants and for motor fuels producers to compensate (in full or in part) for the emissions caused, as well as the possibility to refund the CO_2 levy to companies which are officially committed to reduce GHG emissions by a specific amount by 2020 (reduction obligation). Moreover, penalties are systematically provided for non-compliance with these various provisions. However, annex 2 art. 1 let. b and annex 3 let. b of the CO_2 Ordinance also states that emission reduction certificates and attestations for domestic emission reductions cannot be issued for reductions achieved from projects of biological CO_2 sequestration and geological CCS (cf. also art. 36 par. 3 let. c of the CO_2 Ordinance), thereby constraining the possible role of CCS in the ETS. While all these elements are established by the CO_2 Act and its Ordinance, there is an operational element which potentially concerns CCU which comes from the 1985 Ordinance on Air Pollution Control (OAPC). The OAPC regulates the capture of emissions from concentrated industrial sources and states that

"emissions shall be captured as fully and as close to the source as possible and shall be removed in such a way as to prevent excessive ambient air pollution levels" (art. 6 par. 1 *OAPC* 1985, see also section 2). This provision concerns evidently the CO_2 considered as an air pollutant, in the same category as other air pollutants dangerous for human health.

Institutional elements include:

- *organisation, financial means and other resources*. Provisions which could be applied to CCUS are present in the 2012 CO_2 Ordinance of the Federal Council (*CO_2 Ordinance* 2012);
- *procedural elements*, which are the institutional rules that organize the procedures for the implementation of the PPs. Overall, the procedural elements relative to the CO_2 levy are exposed in the provisions of the mineral oil tax legislation, whereas those for the other operational elements of the PPs (Swiss ETS, obligations to compensate GHG emissions, etc.) are present in the 2012 CO_2 Ordinance.

5.1.4 CONCLUSIVE REMARKS

The current climate change mitigation regulatory framework is the result of the interplay of agreements and strategies at both the international and the national levels. We have shown that CCS and, more generally, NETs are listed among the methods to decrease carbon dioxide levels in the atmosphere, however the role of CCU is still largely unexplored outside the specialized literature. The main reasons for this are that CCU is still relatively new and untested on large scale, generally more complex than CCS, and object of a number of political and ethical concerns that we have tried to resume and address in volume 1, section 2.3. However, the release of the IPCC special report *Global Warming of 1.5°C* (IPCC 2018) and the issues it raised about the urgent action to undertake in order to keep the increase in global average temperature to 1.5°C have strengthened attention about the potential of CCU, therefore it is likely that future IPCC official reports and UNFCCC formal decisions will explicitly address in more detail the issue of carbon dioxide capture and valorization as an additional instrument of climate change mitigation.

ETS and carbon levies are two manners to apply the well-known 'polluter pays' principle of environmental policy to the issue of GHG emissions. It is clear that, as for other low-carbon power technologies (such as wind power, solar power, hydropower, nuclear power, etc.), the competitiveness of CCUS technologies increases when carbon pricing increases, which can help them to take a bigger share in the market. But while other technologies such as solar and wind power are already competitive with fossil resources, mainly because they are incentivized by policies specifically designed for the electricity market (for instance, the retribution at cost price), and do not really need a higher carbon pricing, CCUS technologies are still in an early phase of their development and the introduction of a high carbon price will be able to increase their cost-effectiveness and application scales in the market. The level of increase of the carbon price is matter of political debate everywhere in the world, however as it is shown in Fig. 5.2, the vast majority of the ETS prices and carbon taxes are still well below the carbon price range that would be needed by 2020 to stay consistent with achieving the temperature goal of the Paris Agreement of "well below 2°C": this price range is estimated to be "at least US$40–80/t CO_2 by 2020 and US$50–100/t CO_2 by 2030, provided a supportive policy environment is in place" (Stern and Stiglitz 2017). For instance, while Switzerland carbon tax appears to be even above that range, it covers only a part of the total GHG emissions of the country, and the price of carbon in the Swiss ETS is insufficient to achieve the Paris Agreement goal. Therefore, an adequate increase of carbon pricing is necessary to implement the recommendations of the High-Level Commission on Carbon Prices. In the perspective of the development of a CCUS supportive policy, this carbon price increase should also be able to allow CCS and CCU technologies to be competitive on the market with traditional fossil resources and fossil-based products, in order for a transition in this sector to be financially viable.

It is generally very complicated to calculate exactly what this carbon price should be[25]: it can actually vary widely across countries and be different for each different technology considered. Calculations for the future would also depend on assumptions concerning economics of scale, since CCUS has not yet been implemented on a large scale but rather in the form of pilot projects, and on learning and technological progress (Stern and Stiglitz 2017). However, it is clear from the experts' analysis that the price of carbon must be increased both to reach the range which is recommended to meet the goals of the Paris Agreement and to allow new CCUS technologies to compete on the market against traditional technologies powered by fossil resources.

In conclusion, the CO_2 Act and the CO_2 Ordinance already present, in their current formulation, a number of items and provisions that could possibly apply to CCUS, although these rules were not originally intended for CCUS technologies. However, in order to strengthen the legislative basis at the federal level to promote the development of CCUS in Switzerland, it would be important to reformulate these rules in a less ambiguous language to clarify their meaning when dealing with CCUS technologies. Even better, the amendments should also add specific provisions to the Act, or at the very least the Ordinance, concerning CCUS specifically. In the present form, both the Act and the Ordinance would give the FOEN a large margin of discretion in the approval and the

[25] *Some estimates have been so far proposed for some specific CCS technologies, especially concerning coal-fired and gas-fired power plants in the United States (Stern and Stiglitz 2017). According to the Global CCS Institute, coal-fired generators in the United States retrofitted with CCS would be on par with traditional (without CCS capability) coal and gas generation if carbon were priced between US$48 and US$109 per ton of CO_2 (Irlam 2015). Studies from the U.S. Clean Air Task Force (2013) suggest a similar range: assessed against the displacement of non-CCS coal-fired power supply, CCS appears to provide abatement at between US$65/t CO_2 for a gas-fired power station with CCS to US$115/t CO_2 for a coal- fired power station with CCS (Clean Air Task Force 2013). Rubin, Davison, and Herzog (2015) calculated the cost of CO_2 captured from supercritical pulverized coal plants and geologically stored as between US$46 and US$99/t CO_2 abated, whereas the cost of CO_2 captured from natural gas combined cycle plants and stored in geological reservoirs are between US$59 and US$143/t CO_2 abated (Rubin et al. 2015).*

oversight of possible projects and measures concerning CCUS, as emerges, for instance, from section 5 of the Ordinance, which deals with the delivery of attestations for domestic emission-reduction projects and programmes. A case by case evaluation by the FOEN would be necessary and this could potentially discourage companies from submitting CCUS projects, since their approval would be more uncertain than for measures explicitly listed in the Act such as energy efficiency and renewable energy projects, which benefit from much broader and more recognized legislative bases.

5.2 THE PROPERTY RIGHTS OVER CO_2

As already mentioned in section 3.1, the property rights system in Switzerland has its main origin in the Civil Code (*Swiss Civil Code* 2006), which was introduced in 1912 and has not fundamentally changed since. In this subsection we aim to examine the current state of the provisions which are applicable to CCUS in the domain of property rights: that is, to define the current state of the property rights of the CO_2 when dealing with the capture, the transportation, the storage or the valorization of this gas. In doing so, we will be largely inspired by the analysis conducted in part II, chapter I of Largey 2017, which examines the issue of property rights for the natural element 'air'.

Property rights can be of two types: *personal rights* and *real rights*[26]. Personal rights are the rights (as of personal security, personal liberty, and private property) appertaining to the person. Real rights (or "rights in rem") are rights attaching to corporeal things. In other words, real rights represent a branch of the legal order that governs the control of corporeal things by persons. Real rights include ownership, use, pledge, usufruct, mortgage, habitation and predial servitude.

In private law, the 'thing' designates a delimited and impersonal portion of the material world, susceptible to be the object of human control and

[26] *Here we refer to the terminology used in the context of public policies, not to the most commonly used legal terminology.*

which is not an animal. Five cumulative conditions are therefore necessary to define it (Largey 2017):

1. the corporeal reality, which is admitted for a tangible material object, having a mass;
2. the delimited nature of the object;
3. the possibility of appropriation of the object;
4. the impersonality;
5. the object must not be an animal.

The air is made of the different atmospheric gases, which are distinguishable and identifiable between them. The atmospheric matter has a corporeal existence which allows to fundamentally distinguish it from the wind or the atmospheric space by its static and corporeal quality respectively. The submission of the CO_2 (as one of the components of the atmospheric matter) to the real rights depends on whether or not it has the status of a 'thing' in the legal sense. This issue has been analyzed - for the case of the atmospheric matter in general - in Largey 2017.

First, atmospheric matter has naturally a corporeal existence, although in molecular form (CO_2, O3, N2, etc.). The issue is more complex for what concerns the conditions of delimitation and appropriation.

For what concerns *delimitation*, for gases and liquids which do not possess their own limits, the status of 'thing' is recognized only if they are contained and delimited in a container. This container must itself be a movable or immovable thing. In order to be considered a thing, the corporeal, delimited object must also be susceptible of *appropriation*, in the sense of the possibility of human control which, for gases and liquids, is only conceivable through the appropriation of the container which contains the gas or the liquid. Hence, only CO_2 which has been captured - isolated from the atmosphere - does satisfy to the status of thing, whereas free CO_2 in the atmosphere does not.

As explained in section 3.1, we follow Gerber et al. 2009 to further characterize the property rights over CO_2: they can be divided in *formal* *property rights*, also known as *ownership rights*, which are rooted in private law (the Swiss Civil Code); *use rights*, which reflect private law provisions but are actually based on PPs; and *disposal rights*, which are usually defined by a combination of private and public law provisions. Table 5.2 at the end of this section summarizes the main findings.

5.2.1 THE FORMAL PROPERTY RIGHTS (OWNERSHIP RIGHTS) OVER CO_2

The free CO_2 in the atmosphere

Only the things can be the object of private property. Since it is not a thing, the free atmospheric matter - including free carbon dioxide - cannot. It does not belong to anyone in particular but it is open to the use of everybody. However, as we have seen, when it is captured, it becomes a thing by the physical act of capture. In order to emphasize this peculiar aspect we follow Roten 2000 and Largey 2017 and define the free atmospheric matter in a legal sense as a *(movable) quasi-thing without a master*, where the term "quasi-" allows to avoid all confusion with the term "thing" in this context.

Expressed in terms of wider relevance for private law and international law, the free atmospheric matter can be also defined as a *res communis omnium*, i.e. a thing of the entire community. Only the air which is susceptible of being separated (captured) from the atmosphere becomes a *res nullius*, i.e. ownerless property which is free to be individually acquired by means of *occupatio*. This is governed by art. 718 of the Civil Code ("ownership of an ownerless chattel is acquired by the act of taking it into possession with the intention of becoming its owner").

Following this double set of definitions, we could argue that the legal appropriation (*occupatio*) becomes possible because the free air becomes a thing (a *res nullius*) through the capture. Conversely, it is not because there is a legal appropriation that the atmospheric matter becomes a thing (Largey 2017).

The CO_2 artificially released in the atmosphere

In the context of climate policies, it is important to examine the case in which the carbon dioxide produced by human activities (industrial or private activities) is released in the atmosphere at the end of the process. The atomic composition of carbon dioxide is naturally the same whatever its source is. Could the origin of the free atmospheric CO_2 justify a special legal status for the carbon dioxide which has anthropogenic origin? The answer to this question is potentially interesting for the person responsible for the emission of the CO_2 who might be tempted to claim real rights on his emissions, especially since he could have paid some taxes to emit.

When the CO_2 is produced by technical processes, it is enclosed in installations which constitute as many containers and is therefore a movable thing which is governed by private property laws: the owner of the installations (considered as movable things) is hence the owner of the carbon dioxide enclosed therein as well. Released in the free air, it mingles with the CO_2 already present in the atmosphere.

With the release of the carbon dioxide in the free air, the owner demonstrates his intention of getting rid of it definitively. This voluntary act has a double loss as its major consequence under the perspective of real rights:

- the loss of the chattel ownership, which is regulated by art. 729 of the Civil Code ("Even where possession has been lost, ownership of the chattel is not extinguished until the owner relinquishes his or her right or until another person subsequently acquires ownership"). In the case of the release in the free air, the owner voluntarily gives up the ownership of the CO_2 which does not find any other third party acquirer by joining the atmosphere. The carbon dioxide thereby loses its status of movable thing since it is no longer delimited by a movable container: free in the atmosphere, which is a *res communis omnium*, the CO_2 is submitted to the legal regime applicable to it.

- the loss of the legal status of thing is not explicitly regulated by the law, but stems from the loss of one or more of its qualities. By mingling with other gases in the free air, the carbon dioxide loses its physical limits imposed by the container and therefore its status of thing.

When it leaves its container, is released in the free air and mingles with other molecules of carbon dioxide and of other gases, the CO_2 becomes, as we have seen before, a *(movable) quasi-thing without a master*, impossible to distinguish from the CO_2 which is naturally present in the atmosphere.

As such, there is no legal reason to discriminate between the two (Largey 2017).

The capture of CO_2 in movable containers

The captured CO_2 is considered a thing in the legal sense, nonetheless its legal status remains intimately linked to the container which contains it. As an object which is delimited, corporeal and susceptible of appropriation, a container is a thing in the legal sense. We can distinguish two types of containers: movable containers on one hand, immovable and underground containers on the other hand. Before further investigating these two situations, we focus on the issue of the capture itself.

As we know, there are two ways to capture CO_2: direct air capture (DAC) and capture from concentrated sources, e.g. at the end of tailpipes in fossil fuel power plants, cement plants, petroleum refineries, etc. In both cases the captured CO_2 is enclosed into movable containers.

CO_2 is in principle not captured to be immediately released afterwards, but to pursue an economic or environmental goal that requires its transient or permanent immobilization. In general, after its capture the carbon dioxide is transported in movable containers towards the place of its storage or its utilization. For movable containers, real rights take the specific form of "chattel ownership", which is the ownership related to movable physical objects as defined in art. 713 of *Swiss Civil Code* 2006.

Moreover, according to art. 714 par. 1 of the Civil Code ("Transfer of chattel ownership requires the delivery of possession to the acquirer"), it's the owner of a movable container who enjoys property rights on it. Therefore, the owner of such a container has also real rights on the carbon dioxide contained into it as a movable thing. From a legal perspective, DAC and capture from concentrated sources present the following distinctive features:

- *DAC*. As we have seen before, the CO_2 which is free in the atmosphere is a *(movable) quasi-thing without a master* and the act of its capture through DAC technology transforms it into a *thing* in the legal sense. In this way, the CO_2 can become the object of real rights and therefore the owner of the DAC infrastructure, which operates as a movable container, enjoys chattel ownership over the captured CO_2. This ownership acquisition is governed by art. 718 of the Civil Code. In this particular case, the pathway of the emitted CO_2 is exactly the reverse of that of the CO_2 which is artificially released in the free air.
- *Capture from a concentrated source*. As we have seen in our analysis about the CO_2 artificially released in the atmosphere, the CO_2 which is produced by technical and industrial processes is a movable thing while it is still enclosed in those same technical installations which produced it. The owner of the installations therefore enjoys chattel ownership over the carbon dioxide contained therein. He can transfer such an ownership to a third party acquirer by delivering the chattel to this other person, according to art. 714 par. 1 of the Civil Code. The delivery occurs through capture of the CO_2 by the acquirer at the end of the tailpipe. In the case of integrated plants with CCU (for instance some integrated biorefineries, see e.g. Maity 2015a and Maity 2015b), the original emitter of the CO_2 can also be responsible for its valorization, therefore no chattel ownership transfer is required.

The owner of the DAC installation, or the acquirer of the carbon dioxide from the original emitter, can then either store or use the CO_2 directly in place, if this is possible, or transport it through special pipes to the place designated for its storage or its valorization.

The storage of CO_2 in immovable and underground containers

In the context of CCS, the storage of the CO_2 previously captured usually takes place into large reservoirs underground (geological confinement).

Before the injection of the carbon dioxide in the geological layers, the owner of the captured CO_2 (as a movable thing and temporarily contained in the capture or transportation facilities) is the person who captured it. With the injection of the carbon dioxide underground, the owner demonstrates his intention of getting rid of it definitively. This voluntary act has a double loss as its major consequence under the perspective of real rights:

- the loss of the chattel ownership, which is regulated by art. 729 of the Civil Code ("Even where possession has been lost, ownership of the chattel is not extinguished until the owner relinquishes his or her right or until another person subsequently acquires ownership"). In the case of the injection in geological reservoirs, the owner voluntarily gives up the ownership of the CO_2 which does not find any other third party acquirer by joining the reservoir. The carbon dioxide thereby loses its status of movable thing: stored in the underground, the CO_2 is submitted to the legal regime applicable to it.

- the loss of the legal status of thing is not explicitly regulated by the law, but stems from the loss of one or more of its qualities. By spreading in the geological layers, the carbon dioxide loses its physical limits imposed by the container and therefore its status of thing.

Consequently, there are in general no subterranean containers that can give the CO_2 which is stored in geological layers the legal status of 'thing', with one possible exception: if the carbon dioxide is stored in caverns or an underground space which is clearly delimited and artificially sealed to prevent accidental leakages of the gas, we would actually have such a subterranean container. The latter would not be a movable thing within the meaning of art. 713 of the Civil Code, but a delimited part of the underground. It will therefore be submitted to the legal regime applicable to the underground. In the context of land ownership, it could be qualified as an immovable container, with reference to the definition of immovable property in art. 655 par. 2 sec. 1 of the Civil Code. The situation is different when underground storage is provided by barrels enclosing the captured carbon dioxide: the latter qualifies as a movable thing delimited by the barrels, which are themselves submitted to the legal regime applicable to the underground. But what is this regime?

Private property of the underground space is governed by art. 667 par. 1 of the Civil Code, which states that "land ownership extends upwards into the air and downwards into the ground to the extent determined by the owner's legitimate interest in exercising his or her ownership rights". However, the case law has established that this article, as well as the guarantee of ownership and economic freedom, does not preclude the cantons from introducing what is known as a *régale historique sur les ressources minières* (or *monopole foncier traditionnel*), i.e. the exclusive right of the cantons to exploit underground resources such as mineral resources (*ressources minières*) (Steinauer 1981). These *régales historiques* find their origin in the traditional interpretation of art. 31 of the old Federal Constitution of 1874: the cantons are entitled to introduce them at all times, regardless whether or not they have existed before the Constitution of 1874 (Carrel 2015). However, the legal doctrine is divided about the requirement or not of a sufficient legal basis to establish such *régales historiques*. The legal doctrine is also divided about another issue: could the *régales historiques sur les ressources minières* be extended by cantonal law to the underground storage of captured CO_2? It is no longer a question of considering the exploitation of a deposit in the form of the extraction of certain underground resources, but of the "creation" of a deposit (sometimes the exploitation of a deposit that has disappeared when the space of an exhausted gas or oil well is used) through the use of the resource 'underground' as a place of confinement. Nonetheless, in practice, this *régale historique sur les ressources minières* and other analogous state monopolies offer only limited and theoretical interest for the problem of the underground storage of carbon dioxide, since they can only make sense if the sequestration takes place in the immediate underground extension of the private property of the landowner, to narrow its scope in favor of a "state property". In principle, the storage of CO_2 is feasible only at great depths, where the underground is in any case subject to the control and sovereignty of the cantons (Largey 2017).

Below the boundary defined in art. 667 par. 1, the Swiss Civil Code does not recognize private property. The part of the underground that escapes to the latter, but also to the cantonal *régale historique*, defines the underground "off property". The legal doctrine is unanimous in recognizing a "cantonal control" over it, which is different from both private property and the *régale historique*, and which is governed by the cantonal public law.

However, the utilization of the underground can depend on interests and induce risks that go far beyond cantonal or even national boundaries. This could be the case for some deep drilling, hydraulic fracturing, the exploitation of rare mineral deposits or CO_2 storage. In these domains, for which uniform regulations seem to be necessary, it is desirable that the legislative competence, at least in principle, is the prerogative of the Confederation in accordance with art. 43a par. 1 of the Federal Constitution (*Federal Constitution* 1999).

A new constitutional provision in this direction could be inspired by art. 76 of *Federal Constitution* 1999 about water: even if the cantons have the sovereignty over public water, the Confederation establishes the principles which are applicable to the conservation and the valorization of water resources (par. 2), legislates on water protection (par. 3), defines the limits on the charges that can be levied by the cantons (par. 4) and decides on the rights to international water resources which concern different cantons unable to agree with each other or different States (par. 5). According to another (more centralizing) approach, the *de facto* cantonal monopoly on the deep underground could instead be limited and even largely emptied of its substance by enacting an exclusive federal competence on geological storage of carbon dioxide, in analogy with art. 90 of the Federal Constitution on nuclear energy (Largey 2017).

In conclusion, the carbon dioxide which is stored in the deep underground - either in a subterranean, immovable container like a cavern, or in barrels - is submitted to the same legal regime applicable to the underground "off property" which, according to the current legal consensus, is an element of the public domain under the monopolistic control of the cantonal authorities[27]. In case the CO_2 were instead stored in the immediate underground extension of the private property of a landowner, cantonal monopolies similar to those existing over mineral resources (the *régales historiques sur les ressources minières*) could eventually apply according to a large interpretation of traditional legal provisions: in this case, therefore, the stored CO_2 would legally become a cantonal property.

5.2.2 USE RIGHTS: THE VALORIZATION OF CO_2

In the context of CCU, the captured CO_2 is submitted to a process of valorization which can take different forms, as shown e.g. in Table B.1.

A precise distinction between formal property rights and use rights in this section is somehow blurred, because no explicit public policy of CCU which would attribute use rights over CO_2 exists yet and therefore the use rights are currently formulated solely in terms of the formal property rights which can be deduced from the Swiss Civil Code. However, this is still consistent with the definition of use rights as seen in section 3.1.

We can distinguish two main pathways for CCU: non-conversion uses of CO_2 and utilization of CO_2 as a feedstock for chemicals. Each of these pathways can then be further divided in two sectors, according to whether the storage of the CO_2 is permanent or non-permanent:

[27] *From a legal perspective, what happens if the CO_2 which has been captured and stored in underground reservoirs accidentally leaks up to the ground surface and is released into the atmosphere? In this case, its status changes from an element of the public domain under cantonal control to a (movable) quasi-thing without a master.*

- *Conversion - Non-permanent storage*. The situation in which the CO_2 is subject to conversion processes. During these processes, the CO_2 CO_2 endures chemical reactions which typically break its chemical bonds to form new ones and the carbon atoms are recycled into new, useful products. For example, in a CCU process known as "algae cultivation" CO_2 is absorbed by microalgae which can then be converted into proteins, fertilizers and biomass for biofuels. In this situation, it makes sense to refer to the usual legal regime applicable to movable things. We focus on the carbon atom, the actual valuable resource, rather than on the full compound CO_2. The carbon which at the beginning of the process was covalently double bounded to two oxygen atoms in a molecule of CO_2 and enclosed in a container (e.g. a transportation facility), therefore being a movable thing and the object of a chattel ownership, reacts with other elements or compounds. As a result, the carbon atom ends being bounded to atoms of other chemical elements in a new compound, as a part of a new product. This product, if valuable, will typically be enclosed in containers in the installation where the conversion process occurs, which make it a movable thing as well. Therefore, the owner of the elements or the compounds which react is also the owner of the final product as well as of any by-products. At the end of the lifetime of the product, the carbon atom will be typically released back in the atmosphere: therefore, it will lose its status of movable thing to become a (movable) quasi-thing without a master.

  Case of different owners. A peculiar case would be the one in which the owner of the carbon dioxide and the owners of the other elements or compounds with which the reaction occurs are different persons. In this case, the final product, a chattel, would be a combination of chattels belonging to different owners and therefore art. 727 of the Civil Code would apply. Par. 1 states that "if chattels belonging to different owners are mixed or joined together such that they may no longer be separated without substantial damage or prohibitive labour and expense, those involved acquire joint ownership rights in the new object in proportion to the value of the constituent parts at the time that they were mixed or joined". This paragraph would concern e.g. the case of CO_2 and hydrogen catalytically converted to methanol. Par. 2 states that "if one chattel is mixed with or joined to another such that it acquires the character of a secondary component of the latter, the entire object belongs to the owner of the primary component". This paragraph would concern e.g. the case in which the captured CO_2 is re-used in greenhouses or for algae cultivation, that is, the biological conversion case. Therefore, we would have, in the first case, a joint ownership of the final product (e.g. the case of the CO_2 fuel), whereas in the latter, the chattel would have the same owner as before the CCU process (e.g. the case of the plants in a greenhouse with CO_2 enrichment). As a general rule, a joint ownership takes place if the final chattel has its fundamental properties altered by the reaction with the CO_2, whereas when the principal chattel is not altered by such a chemical reaction, its original ownership is maintained.

- *Non-conversion - Permanent storage*. The situation in which the CO_2 is not chemically converted and therefore the carbon atom remains bounded into the CO_2 compound after the process. For instance, in Enhanced Oil Recovery (EOR) processes, the captured carbon dioxide is injected in a liquid-like state into an existing oil well reducing the viscosity of the oil, therefore increasing the amount of oil that can be produced from the well. Most of the CO_2 injected into the well becomes trapped in the rock and is permanently stored in the pore spaces, whereas the portion of the injected CO_2 which is recovered with the oil is immediately separated and combined with CO_2 arriving from the original source for re-injection into the formation. Ultimately, all the CO_2 injected in the well will be permanently stored in the formation. In this case, the carbon dioxide loses its original status of movable thing over which the owner of the installation which contained it enjoyed a chattel ownership, mirroring faithfully the case of the injection in geological reservoirs explored in one of the previous sections, "The storage of CO_2 in immovable and underground containers". Hence, stored in the underground, the CO_2 is submitted to the legal regime applicable to it, which was analyzed in one of the previous sections as well. We can conclude that in the case of non-conversion of CO_2 with permanent storage, such as EOR, the real rights of carbon dioxide take the same form as in the case of CCS.

Case of different owners. If the owner of the oil and the owner of the CO_2 used in the EOR process are different, the mixture of oil and CO_2 in the well and before the separation of the two substances is subject to art. 727 of the Civil Code, either to par. 1 or to par. 2 according to the amount of CO_2 actually present in the mixture.

- *Conversion - Permanent storage*. In mineralization processes, e.g. carbon mineralization, carbon dioxide chemically reacts with other compounds, generally calcium- or magnesium-containing minerals, to produce new compounds which can be used e.g. as a construction material. In this case, the carbon atom is permanently stored in this new material. This material is a movable thing and the object of a chattel ownership which can be acquired and sold, therefore the owner of the compounds which gave origin to the final construction product is also the owner of this product, which can be sold in the marketplace and acquired by a new owner. The legal status of chattel is therefore never lost, unless the final product becomes an integral part of a building, which, according to art. 655 par. 2 of the Civil Code, is not a chattel but "immovable property".

  Case of different owners. A peculiar case would be the one in which the owner of the carbon dioxide and the owners of the other elements or compounds with which the reaction occurs are different ones. In this case, the final product, a chattel, would be a combination of chattels belonging to different owners and therefore art. 727 of the Civil Code would apply. More specifically, par. 2 would apply, since carbon dioxide is a secondary component of the reaction in a carbon mineralization process, the primary ones being calcium- or magnesium-rich minerals. Hence, the final material would belong to the owner of the minerals.

- *Non-conversion - Non-permanent storage*. In desalination processes, CO_2, mixed with H_2O brine at high pressure and low temperature, forms a hydrate of CO_2 surrounded by H_2O molecules. The hydrate is removed and rinsed, and then goes through multiple stages to remove dissolved solids in the brine, resulting in an exhaust stream of potable water (Nemitallah et al. 2019). The brine is then disposed. In this example, the owner of the carbon dioxide (who can be the person who captured it or an acquirer) enjoys chattel ownership over it until the CO_2 is disposed and ultimately released after the desalination process, when it loses its status of thing.

  Case of different owners. A peculiar case would be the one in which the owner of the CO_2 and the owner of the other compounds involved in the process (e g. H_2O in the case of desalination) are different ones. In this case, the new chattel formed during the process would be a combination of chattels belonging to different owners and therefore art. 727 of the Civil Code would apply (whether par. 1 or par. 2 applies, this specifically depends on the process considered). There would therefore be a joint ownership e.g. over the hydrate of CO_2 surrounded by H_2O molecules. This would however be only temporary, since this combination of chattels fragments or dissolves with the completion of the process.

5.2.3 DISPOSAL RIGHTS OVER CO_2

As we said in section 3.1, disposal rights concern the transfer of the formal property title of an object that is owned. In this sense, disposal rights concern any transfer of CO_2 property rights, which can occur during many parts of the CCUS processes, whenever the owner of a certain amount of CO_2 transfers his rights over it to a third parts acquirer. These rights are normally rooted in formal property rights: we have indeed seen in section 5.2 that transfer of chattel ownership, as defined in art. 714 par. 1 of the

Civil Code, constitutes the foundation of any real rights over transfer of property titles of movable physical objects.

However, as we have seen in section 4.2, in order to correctly identify the IRR governing the use of carbon dioxide in Switzerland, we must consider not only CO_2 as a resource in itself, but also CO_2 (emissions) as modification of another resource, the climate. Indeed, it is the environmental risk associated with the anthropogenic greenhouse effect that have brought to the establishment, in recent times, of public policies creating *property rights for pollution* as distinguished from *property rights for natural resources*, see e.g. Devlin and Grafton 1998. Compared to the latter, property rights for pollution are often identified by very specific characteristics: namely, that these rights are transferable and that a "market" is established wherein the "rights to pollute" can be traded. Therefore, *when we consider CO_2 of anthropic origin as pollution, property rights are affected not only by provisions of the Civil Code but also by provisions of existing PPs*. As reported in section 5.1.3, a Swiss market to trade emission allowances, i.e. the rights to pollute by emitting GHGs in the atmosphere, has been actually established by the CO_2 Act, which has introduced these rights to pollute under the form of "allowances".

The main alternative provided by the CO_2 Act to allow polluting installations to emit GHGs in the atmosphere, i.e. the carbon levy (see section 5.1.3), is similar to the ETS in the sense that it also applies the "polluter pays" principle to carbon dioxide emissions and quantifies the "cost" of such pollution in 120 francs per tonne of CO_2 (as of 2019). However, the carbon levy is also different from the ETS since no trading of "rights to pollute" is involved.

Property rights over CO_2	
Formal property rights (ownership rights)	
CO_2 in the atmosphere	CO_2 is a (movable) quasi-thing without a master
CO_2 enclosed in a container (either captured or produced by technical processes)	CO_2 is a thing over which the owner enjoys a chattel ownership
CO_2 stored underground as in CCS	CO_2 is an element of the public domain under the monopolistic control of the cantonal authority
Use rights for CO_2 as a resource: CO_2 valorized as in CCU	
Conversion - Permanent (e.g. carbon mineralization) or non permanent (e.g. algaecultivation) storage	C atom is a (movable) thing over which the owner enjoys a chattel ownership
Non conversion - Permanent storage (e.g. enhanced oil recovery)	As in "CO_2 stored underground as in CCS" (see above)
Non conversion - Non permanent storage (e.g. desalination processes)	CO_2 is a (movable) thing over which the owner enjoys a chattel ownership
Disposal rights for CO_2 as pollution	
CO_2 released in the atmosphere by emitting installations	The CO_2 Act establishes a levy over carbon emissionsor, alternatively, a market of "rights to pollute" or "emission allowances". The payment of the levy or the purchase of an adequate number of allowances effectively allows an installation to emit CO_2 in the atmosphere asa pollutant.

Table 5.2: Summary of the property rights over CO_2 in the current legal framework.

6 THE IMPLEMENTATION OF THE REGIME

In this chapter, we continue to describe the empirical research procedure in six steps in the case of the IRR framework for a prospective CCUS development, as outlined in section 3.2. In particular, we aim to analyze the implementation of the resource regime described in chapter 5, i.e. the possible interactions between the different groups of users of the resource CO_2 and the authorities in charge of the regulation of the use of the resource, as well as the rivalries which could rise should CCUS technologies be deployed on a large scale. Our approach, as already stated, is prospective, since CCUS development in Switzerland is still in its infancy. Therefore, in the absence of a specific Swiss public policy on CCUS, we limit ourselves to a prospective inquiry of the existing legislative provisions over carbon dioxide, in order to investigate their possible contributions to a regulation of the rivalries between the policy actors which would be involved in a hypothetical CCUS development in Switzerland. In this perspective, we embed the concept of CCUS into the existing Swiss climate policy which is mainly defined by the CO_2 Act.

6.1 THE BASIC TRIANGLE OF POLICY ACTORS

The elaboration of a public policy occurs in a space where the decisive interactions between the actors of the public policy unfold. The various policy actors can be placed in a "basic triangle", a conceptual instrument which helps visualize and understand these interactions (see e.g. Peter Knoepfel et al. 2007).

6.1.1 THE POLICY PROBLEM AND ACTORS

The policy actors involved in the deployment of CCUS in Switzerland have already been identified in volume 1, chapter 3, in relation to each part of the CCUS processes. Here we attribute them to the three categories of actors that one can distinguish in the basic triangle. These categories are:

- the *political-administrative authorities*, who develop and apply the public policy. The main federal offices that are the most involved in the public policies for the deployment of CCUS are the Federal Office for Environment (FOEN), the Swiss Federal Office of Energy (SFOE), the Federal Office of Transport (FOT)[28] and some offices in the Federal Department of Economic Affairs, Education and Research (in particular Innosuisse, the Swiss Innovation Agency);
- the *target groups*, who cause the collective problem that the public policy seeks to solve. In this case, the collective problem to solve with CCUS is two-folds and can be described as *risk for groups who are victims of the negative effects of climate change as well as for groups who are victims of the excessive dependence of Switzerland on imports of various resources, particularly fossil resources, for the manufacture of certain products*. Thereby, the target groups are the companies which import and use these resources in place of carbon dioxide to build their products as well as the companies which emit CO_2 in the atmosphere instead of recycling it or storing it, such as the electric power utilities using fossil resources;
- the *end beneficiaries*, who suffer the negative effects of the problem: the Swiss population and the rest of the world, the ecosystems, as well as the companies now highly dependent, for the manufacture of their products, on imports of resources that can by replaced by carbon dioxide through CCU processes.

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[28] *Under the Federal Council's Energy Strategy, the FOT has launched the Energy Strategy for Public Transport 2050 (ESPT 2050) programme. Its goals are to increase energy efficiency, opt out of nuclear energy, reduce CO_2 emissions and produce renewable energy.*

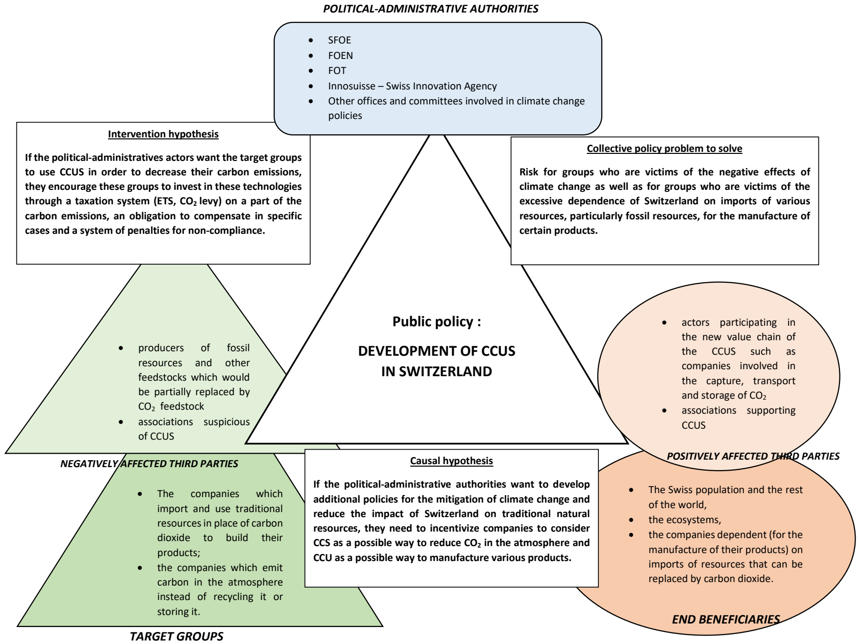

Figure 6.1: The basic triangle for the public policy on CCUS.

In addition to these three groups, there are some private actors, the third parties, indirectly affected by the public policy which are located on the periphery of two of these three poles: the *negatively affected third parties* and the *positively affected third parties*, namely the groups which are negatively affected by the implementation of the public policy, and those which are positively affected by the implementation of the public policy, respectively. In this case, the negatively affected third parties would be the producers of fossil resources and other feedstocks which would be partially replaced by CO_2 feedstock, as well as the as the associations and foundations that support climate change mitigation policies but are suspicious of CCUS. On the other hand, the positively affected third parties would be the actors participating in the new value chain of the

CCUS such as companies involved in the capture, transport and storage of CO_2, as well as the associations and foundations (e.g. some NGOs) that support climate change mitigation policies which include the use of CCUS.

Moreover, if the public policy designed to develop CCUS in Switzerland also foresees an increase in the federal carbon pricing in order to increase economic profitability of CCUS applications, other negatively affected third parties would be the firms subject to the CO_2 levy or the ETS, whereas the general population would be only mildly impacted by this increase if (as it is currently the case) most of the revenues of the CO_2 levy are then redistributed to the population.

6.1.2 THE CAUSAL HYPOTHESIS

Defining the causal hypothesis of a public policy means, for the political-administrative authorities, designating the target groups and final beneficiaries of the policy by answering the question: “Who is responsible for the collective policy problem which is necessary to solve?”. The identification of such a responsibility derives from the scientific assessments on the causes of anthropogenic climate change (see e.g. Charney et al. 1979) which, in turn, has led to a political effort by the international community to address this issue and mitigate its most dreadful effects, an effort which has notably led to the signature of the Paris Agreement in 2015. The Swiss federal policy on climate change mitigation is clearly rooted in this ground and is therefore well established according to the general scientific and policy framework. Hence, *if the political-administrative authorities want to develop additional policies for the mitigation of climate change (in line with the goals of the Paris Agreement) in the area of CCUS and reduce the impact of Switzerland on traditional natural resources by starting considering carbon dioxide as an alternative resource, they need to target companies, in order to make them consider CCS as a possible way to reduce CO_2 in the atmosphere and CCU as a possible way to manufacture various products, diverting* *from more fossil-intensive ways of production and diminishing emissions of carbon dioxide in the atmosphere.*

6.1.3 THE INTERVENTION HYPOTHESIS

The intervention hypothesis establishes how the policy problem can be solved, or at least mitigated, by the policy which is proposed. This hypothesis defines the modalities of the State intervention which are meant to influence the activities of the target groups, in such a way that their behaviour becomes compatible with the goals of the public policy.

Following the analysis of section 5.1.3, we investigate what are the main instruments of intervention, derived from the existing legislation, that the Swiss public authorities can use to influence the activities of the target groups and make them compatible with the climate policy goals. As we already said, the vast majority of the "operational elements" listed in Table 5.1 have been designed without taking into account either CCS or CCU. Hence, the question becomes: if the public authorities wanted the target groups to start using CCS and/or CCU in order to decrease even more their carbon emissions than with the energy transition alone, to what extent can the existing climate policy provisions influence these groups to use these new sets of technologies? In our opinion, the answer can be derived from the discussion contained in section 5.1.3.

- For the CCS part, we believe that the existing legislative provisions contained in the CO_2 Act could bring a certain level of deployment of these facilities in the medium term, provided that the technological advancement brings down the cost of the installation of the CCS infrastructure in the medium-term future. One of the main reasons for that is that a methodology to estimate carbon emissions from CCS facilities is already present in the IPCC guidelines for the national GHG inventories (IPCC 2006), thus allowing emitting installations to quantify with a good degree of precision the emission savings which could derive from the installment of such an equipment, by comparing their carbon emissions with and without CCS. Given that the enactment of the CO_2 Act is a direct consequence of the international engagements taken by the Swiss Confederation under the UNFCCC whose progressions have to be reported following the IPCC guidelines, CCS-derived emission savings can be officially recognized at the international level in the current legislative framework.

- On the other hand, the IPCC guidelines do not include a methodology to evaluate carbon emissions resulting from CCU processes, which can be very complex. Therefore, companies are not particularly encouraged to decrease their emissions through CCU by the existing policies. Nevertheless, even in the absence of new legal provisions, companies could find a purely economic incentive in recycling their CO_2 emissions or in using recycled CO_2 in case technology developments would make the cost of installing and running CCU equipment competitive with conventional fossil resources. However, this is not likely to happen on a widespread scale in the short- or medium-term future.

In both cases, the mechanism of carbon pricing established by the CO_2 Act is an instrument which is *a priori* essential to encourage the storage or recycling of carbon emissions. However, as exposed in chapter 5, this mechanism is still not stringent enough to make CCUS financially viable.

It is also worth noticing that the CO_2 Ordinance explicitly bars emission reductions achieved from projects of biological CO_2 sequestration and geological CCS from being eligible for the issue of emission reduction certificates in the context of the Swiss ETS, see section 5.1.3. This means that geological CCS and some NETs such as afforestation can only be used by companies participating in the ETS to *actively reduce* their own emissions, thereby allowing these companies to decrease the number of purchased emission allowances or to sell the ones they already own. Such projects cannot, however, be used to *compensate* the emissions of ETS companies through the surrender to the Confederation of emission reduction certificates or attestations for domestic emission reductions related to these projects[29] in the context of the ETS. However, while this provision constitutes certainly a restriction in policy support to CCS development, it does not completely prevent CCS processes from being considered as emission reduction techniques in the Swiss legal framework.

In this context, i.e. in the absence of a strong and well-defined public policy on CCUS, a quite relevant role could be played by other actors such as NGOs, e.g. the Global CCS Institute or CO_2 Value Europe. In fact, these organizations have been created to address the most important issues facing CCS and CCU industries and their reports, conferences and other forms of intervention in the public debate could be useful in order to raise awareness among private companies of the opportunities offered by the introduction of CCUS technologies in Switzerland.

For what concerns the public authorities, the intervention hypothesis could therefore be formulated in this way: *if the public authorities want the target groups to use CCUS in order to decrease their carbon emissions, they encourage these groups to invest in these technologies through a price or taxation system (ETS, CO_2 levy) on a part of the carbon emissions, an obligation to compensate in specific cases and a system of penalties for non-compliance*. However, since a direct recognition of CCUS-derived emission savings is almost completely absent in the federal legislation, these intervention instruments appertain more to an incitement modality than to a rigorous regulation, if we consider them from the perspective of an actual public policy of CCUS.

6.2 CONCLUSIVE REMARKS

In this chapter, which deals with a whole step of our IRR analysis of CCUS in Switzerland, the implementation of the regime of the resource CO_2, we have tried to 'embed' the development of CCUS into the existing climate legislative framework in order to apply the "basic triangle" of

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[29] *Emission reduction certificates are internationally recognized documents designated to attest to reductions in emissions achieved abroad, see art. 2 par. 4 of the CO_2 Act.*

policy actors. This is a causality model which can help to identify the actors involved in a public policy and to analyze the relationships between them, which is the actual goal of this part of the IRR. Since the scope of the whole IRR analysis in this work is to analyze the extent and quality of a possible regulation of CCUS through the existing legal provisions (especially the CO_2 Act), this basic triangle does not deal with a comprehensive public policy of CCUS, which has yet to be fully developed. Rather, it analyzes in a prospective manner the form that relationships between the actors of CCUS development can take in the existing legislative framework.

This analysis has allowed us to regroup the main policy actors (which we had already identified in volume 1, chapter 3) into various categories: political-administrative authorities, target groups, end beneficiaries and third parties (both positively and negatively affected). This distinction already permits a first appraisal of the interactions between all the actors. The causal hypothesis is predominantly based on the scientific findings on climate change according to which international and national climate policies have been shaped, thus this part of our analysis is very little affected by the current lack of a unifying Swiss policy on CCUS.

Not surprisingly, the intervention hypothesis shows the scarcity of the instruments which can be used by the public authorities to steer the activities of the target groups towards CCUS development if we limit ourselves to the existing legal provisions. Interestingly enough, the current situation shows that the interactions between positively affected third parties (e.g. associations supporting CCUS) and the target groups could partially compensate for the weakness of the public intervention in the matter, accelerating the deployment of CCUS technologies.

7 THE EXPECTED IMPACTS OF THE REGIME ON THE RESOURCE AND TEMPORAL CHANGES

In this chapter, we deal with the last two steps of the empirical research procedure outlined in section 3.2, which are intended to analyze the possible outcomes of the resource regime previously described with respect to the level of sustainability of the use of the resource as well as the prospective evolution of the resource regime to temporal changes. Normally the set of laws and regulations put in advance in an IRR framework are meant to improve the sustainability in the utilization of a given natural resource by overseeing and restricting the access to this resource and its consumption. The case of the resource "CO_2" is peculiar because of its triple nature of resource, waste and air pollutant, as examined in section 2, and also because the large-scale development, on both the commercial side and the policy side, of a business based on CO_2 valorization is still lacking. While other natural resources such as soil or water are endangered by human over-consumption in such a way that scarcity and degradation are the main issue facing the sustainable use of these resources, because of human activities the concentration of carbon dioxide in the atmosphere and in the oceans has not ceased to increase since the Industrial Revolution. This sharp rise, which is the cause of the anthropogenic greenhouse effect, is directly and indirectly linked to the deterioration of other sustainability indicators, since CO_2 is also a waste and an air pollutant. This is the reason why the main goal of the current IRR regulating carbon dioxide use in Switzerland is to reduce the anthropogenic CO_2 emissions. A much more ambitious, longer-term, and still officially unexpressed goal would ultimately be to decrease the concentration of CO_2 in the atmosphere to bring it back to pre-industrial levels. In order to do so, a large scale deployment of CCUS technologies, not limited to Switzerland, would be necessary. Whenever such a goal is reached and a business for CO_2 valorization is firmly established, with an important reduction of atmospheric CO_2, the legal status of carbon dioxide as an air pollutant, and possibly a waste, will become largely academic and without practical relevance. This situation will fully allow CO_2 to be considered as a valuable renewable resource and issues of scarcity will start to play a role since the valorization and exploitation of this resource in a business-driven context will need to be balanced with the necessity to stabilize the atmospheric concentration of the resource, according to an approach similar to the sustainable management of soil or water. In fact, if different companies compete for a resource which must not be further depleted, stronger regulations will need to be called for: however, possible anthropogenic sources of CO_2 are so widespread nowadays that a real problem of scarcity of this resource is unlikely to arise, even in a post-climate change world.

8 ANALYSIS OF THE INTEGRATION AND THE CONSISTENCY OF THE IRR

In this chapter, we seek to investigate the barriers that the current institutional and legal framework presents for the development of CCUS technologies in Switzerland, both in the sector of public policies (PPs) and in the sector of property rights (PRs) that we presented in the previous chapters. In particular, as a complementary inquiry to the analysis conducted in chapter 5 in which we described the opportunities offered to CCUS by the ongoing public policies, in this chapter we choose to identify the gaps existing in the current policies.

The IRR framework can describe the different configurations of institutional resource regimes, based on the two dimensions of extent and coherence, and the typology of the four regimes that results from it and which is depicted in Fig. 8.1. It assumes the existence of a causal relationship between the type of regime, defined by its degree of scope and coherence, and the sustainability of resource use. In other words, the more a resource regime is integrated (high scope and coherence), the higher the chances of creating conditions of sustainable use of the resource. Conversely, the less integrated the regime is, the less coherence and scope, the greater the risk of unsustainable use of the resource. In fact, as already explained in chapter 3, according to the IRR approach, the respect of social, economic and environmental sustainability criteria at the level of the different uses of the resource is not sufficient to guarantee its sustainability. In general, an integrated resource regime taken in its globality implies a coordinated regulation of all uses so that the stock of the resource is not over-exploited. Such coordination presupposes that the (integrated) institutional regime of the resource is capable of transcending the sectoral uses resulting simultaneously from the exploitation policies (agriculture, infrastructure, industry, transport, etc.) and protection policies (environment, nature, landscape, biodiversity, etc.) of the resource (Nahrath and Gerber 2014).

The case of CO_2, as we have already seen, is peculiar with respect to more traditional natural resources (e.g. fish fauna, forest resources, etc.), since we are currently dealing with an overabundance, and not an over-exploitation, of carbon dioxide in the atmosphere, a situation which enhances the greenhouse effect. Therefore, the "unsustainable use of the resource" in this particular case of overabundance of carbon dioxide should rather be referred to another natural resource, the climate, which is affected by the greenhouse effect (as discussed in chapter 3: *"the IRR of CO_2 has to be meant as the ÌRR of the resource 'carbon dioxide' in the context of the protection of the resource 'climate' "*).

In detail, the four distinct types of regime are (Gerber et al. 2009):

- *Non-existent regime*: in this regime, either the resource does not have any kind of property right associated with it, or its goods and services are not subject to any kind of regulation.
- *Simple regime*: in this regime, a limited number of goods and services are regulated in a coherent way; the coherence of the regime results specifically from the low number of regulations in force and therefore the low risk of contradiction between them.
- *Complex regime*: in this regime the majority of the goods and services actually used are regulated, but in a way that is incoherent in part.
- *Integrated regime*: in this regime all of the goods and services produced by a resource are regulated in a coherent way.

In order to determine to which of these four typologies the IRR of CCUS belongs, we need to determine what is the degree of coherence between the provisions of the different PPs and PRs relevant to CCUS, including those related to the legal status of the carbon dioxide.

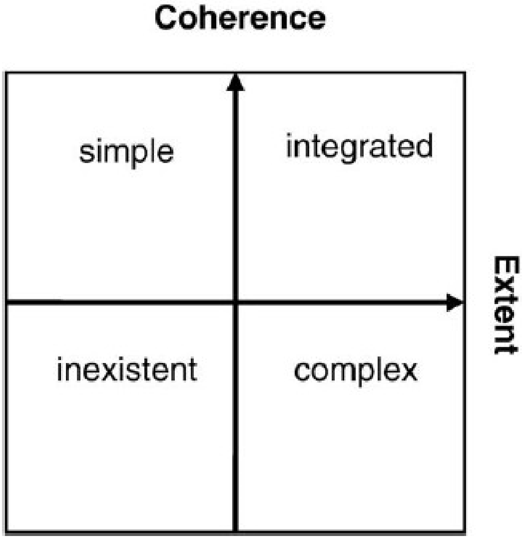

Figure 8.1: Typologies of Institutional Resource Regimes according to their extent and coherence. Source: Gerber et al. 2009.

8.1 THE COHERENCE OF THE LEGAL STATUS OF CO_2

As it can be seen from Table 2.1 and from the analysis conducted in chapter 2, to which we refer here, the main gaps and inconsistencies present in the current legal status of CO_2 are the following:

- One of the biggest issues to be solved concerns the differentiation which is made between the legal status of the free atmospheric CO_2 whose origin lies in the natural carbon cycle of the Biosphere and the CO_2 present in the atmosphere which is produced by the burning of fossil fuels and is therefore inserted in the anthropogenic carbon cycle. In particular, according to both EU and Swiss public law, CO_2 is an air pollutant only when of anthropic origin. However, as we wrote in section 5.2, "the atomic composition of carbon dioxide is naturally the same whatever its source is. Could the origin of the free atmospheric CO_2 justify a special legal status for the carbon dioxide which has anthropogenic origin? The answer to this question is potentially interesting for the person responsible for the emission of the CO_2 who might be tempted to claim real rights on his emissions, especially since he could have paid some taxes to emit". In our opinion, this differentiation is not very suitable to the introduction of many CCUS applications in the policy and economic system. For instance, DAC installations capture atmospheric CO_2 which is then stored or valorized regardless of its origin: it is of course impossible to know whether the carbon dioxide which is captured is to be considered, according to the current legal status, as "air pollution" (produced by the burning of fossil fuels) or not. However, this fact would possibly become relevant for the recognition of an environmental role played by DAC projects, which would obviously depend on the recognition of the captured CO2 as an air pollutant or not. Therefore, it is important to remove possible ambiguities on a practical level concerning the legal status of carbon dioxide as a pollutant.

- The possible status of "resource" for CO_2 in the perspective of CCU applications is still largely unexplored in both EU and Swiss public law, although possible definitions have been proposed, e.g. Nahrath and Gerber 2014 which follows the same sustainability principle of art. 73 of the Federal Constitution on the equilibrium of the relationship between nature and the human population. We also notice that the definition of "by-product" in EU law[30] is quite similar to the

[30] *The definition of "by-product" is provided in art. 5 par. 1 of the Directive 2008/98/CE, which states that "a substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as not being waste [. . .] but as being a by-product only if the following conditions are met: (a) further use of the substance or object is certain; (b) the substance or object can be used directly without any further processing other than normal industrial practice; (c) the substance or object is produced as an integral part of a production process; and (d) further use is lawful, i.e. the substance or object fulfills all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts" (*Directive 2008/98/EC *2008).*

concept of resource, but limited to the case in which it is a substance resulting from a production process. Instead, a resource is such even *in potentia*: CO_2 is a natural resource even in the atmosphere, since the society can in principle capture and valorize it through DACCU for various goods and services.

- In Swiss public law, the concept of "waste" is strictly connected to the one of "movable object", whereas in EU public law it is not. The Swiss definition can bring to some conceptual inconsistencies: for example, the carbon dioxide stored before being released into the atmosphere is considered as waste, whereas the CO_2 which passes through a chimney before being directly emitted is not.

In general, the provisions contained in the EPA target "traditional" air pollutants such as nitrogen oxides (NO_X), carbon monoxide (CO) or particulate matters, which are directly toxic to human health. On the other hand, as already said in chapter 2, it is not CO_2 itself which is dangerous to human well-being (it is, instead, a natural component of the atmosphere, essential for plant life and given off by the human respiratory system), but its increasing concentration in the atmosphere due to deforestation and consumption of fossil fuels which enhances the greenhouse effect which is in turn potentially dangerous for the sustainment of human life on Earth. Furthermore, while the natural occurrence of carbon dioxide does not differentiate it from some traditional air pollutants (particulate matter, for instance, can also occur naturally when they are originated from volcanoes, dust storms, etc.), the fact that the desirable or ideal condition to obtain is a pre-industrial (non-zero) concentration of carbon dioxide in the atmosphere is strikingly different from the usual ideal condition for most air pollutants, namely a concentration of these pollutants approaching zero.

Therefore, the EPA provisions are at the origin of the main inconsistencies regarding the legal status of CO_2 because they were written at a time when climate change was still not a matter of policy concerns, not even in the environmental sector. The definition of "air pollutant" is incomplete with respect to the necessity of the integration of carbon dioxide in the list of air pollutants, since it takes into account only the carbon dioxide of anthropogenic origin (art. 7 par. 3 EPA). Moreover, the Swiss legal definition of "waste" which is at the source of the inconsistencies reported above, because of the connection between "waste" and "movable object", is also contained in the EPA (art. 7 par. 6 EPA).

8.2 THE COHERENCE OF THE PUBLIC POLICIES AND THE PROPERTY RIGHTS SYSTEMS

In this section, as a conclusion of the IRR analysis conducted in chapter 5, we classify the existing PPs and PRs regulations which can be related to each step of the CCUS processes (namely the capture, the storage and the utilization). The purpose is twofold: on one hand, we aim to identify the parts of the IRR which are still missing in order to enable a full and coherent development of CCUS technologies; on the other hand, we would also like to analyze the level of (in)consistency of the current IRR of CCUS, with reference to the IRR typology scheme depicted in Fig. 8.1.

8.2.1 THE CO_2 CAPTURE IN THE IRR

- *PPs*. As we have seen in section 5.1, the capture from concentrated industrial sources is regulated in the 1985 Ordinance on Air Pollution Control (OAPC), which states that "emissions shall be captured as fully and as close to the source as possible and shall be removed in such a way as to prevent excessive ambient air pollution levels" (art. 6 par. 1 *OAPC* 1985, see also section 2.1). This provision concerns evidently the CO_2 considered as an air pollutant, in the same category as other air pollutants dangerous for human health. One should verify whether this fact could potentially lead to a conceptual inconsistency in the context of CCU, since in this case the status of CO_2 as a resource, and not as an air pollutant, would apply in the first place. Therefore, one could eventually need to expand the regulation of the capture beyond the description of the OAPC and the environmental concerns to include the case in which the reason for the capture would be purely economic. Moreover, this provision does not seem to refer directly to DAC, since DAC technologies by definition do not capture emissions close to the source.

- *PRs*. The DAC is governed by art. 718 of the Civil Code, whereas the capture from a concentrated source is governed by art. 714 par. 1 of the Civil Code (see also section 5.2).

8.2.2 THE CO_2 TRANSPORT IN THE IRR

- *PPs*. There are currently no provisions concerning the transport of the captured carbon dioxide, for example to transport it to a storage site[31].
- *PRs*. The Swiss Civil Code contains provisions which can be related to the transfer of PRs when dealing with the transport of CO_2. In this case, in fact, the general rules of the Swiss Civil Code related to the transfer of movable property, or chattel, apply. This is regulated by art. 714 par. 1 of the Civil Code. The transfer of the property is done by the transfer of the 'possession'. 'Possession' means the effective control of the chattel (cf. art. 919 par. 1 of the Civil Code). This presupposes a *de facto* mastery (objective condition) and the willingness (subjective condition) to possess. In practice, the ownership of the transported CO_2 is transferred to the purchaser when the latter exercises effective control of the gas (when entering its facilities or tanks) and wishes to have possession of it. This case is analogous to the case of carbon capture from a concentrated source seen above.

8.2.3 THE CO_2 STORAGE IN THE IRR

- *PPs*. As explained in section 5.1.4, while there is no explicit mention of CCS in the 2011 CO_2 Act or in the 2012 CO_2 Ordinance, the aim of the Act ("to reduce GHG emissions", art. 1 par. 1) and measures such

[31] *The 1963 Pipeline Transport Facilities Act (*Federal Act on Pipeline Transport Facilities *1963) and the 2000 Ordinance on Pipeline Transport Facilities (*Ordinance on Pipeline Transport Facilities *2000) in their current state only apply to pipes used to transport mineral oil, natural gas or any other liquid or gaseous thermal or motor fuel.*

as the concept of compensation of GHG emissions (section 4.2 of the Act) are technology-blind and hence implicitly allow to consider CCS among the various possible tools for emissions reduction. Other technology-blind measures which can favor CCS applications are those outlined in art. 4 par. 2, section 4.2 and section 4.3 of the CO_2 Act and in art. 83 of the CO_2 Ordinance. Nonetheless, many possible measures are still missing from the official climate policy.

As already discussed in section 5.1.3 and in section 6.1.3, the CO_2 Ordinance puts some restrictions on the possible use of geological CO_2 sequestration projects for the issue of emission reduction certificates and attestations for domestic emission reductions in the ETS. However, such restrictions are not to be considered as a disavowal of CCS but rather as a first, partial attempt of regulation of this sector, in the absence of a larger public policy governing it.

- *PRs*. As analyzed in section 5.2, when the CO_2 is injected and stored in the underground, the chattel ownership of the CO_2 is lost and the CO_2 becomes subject to the legal regime applicable to the underground, which is not exactly defined either in the Civil Code nor in the Federal Constitution but which, according to the current legal consensus, could presumably be the monopolistic control of the cantonal authorities. However, the lack of an unequivocal regulation concerning the property rights of the underground is a factor of risk and menaces the large scale development of storage options in Switzerland. In addition, the lack of clear liability rules concerning possible leakage in the near future of the CO_2 stored could deter companies from developing CCS projects in Switzerland.

8.2.4 THE CO_2 UTILIZATION IN THE IRR

- *PPs*. Similarly to CCS, as explained in section 5.1.4, while there is no explicit mention of CCU in the 2011 CO_2 Act or in the 2012 CO_2 Ordinance, the aim to the Act ("to reduce GHG emissions", art. 1 par. 1) and measures such as the concept of compensation of GHG emissions (section 4.2 of the Act) are technology-blind and hence implicitly allow to consider CCU as well as CCS among the various possible tools for emissions reduction. Other technology-blind measures which can favor CCU applications are those outlined in art. 4 par. 2, section 4.2 and section 4.3 of the CO_2 Act and in art. 83 of the CO_2 Ordinance. However, many of them are still missing from the official climate policy. Furthermore, the CO_2 Ordinance requirement that emission reductions must be "verifiable and quantifiable" (art. 5 par. 1 sec. c of *CO_2 Ordinance* 2012) favors CCS over most of CCU techniques (see section 5.1.4).

- *PRs*. As analyzed in section 5.2, the PRs in the majority of the utilization processes (user rights) are generally based on chattel ownership of the CO_2 and its possible transfer, especially regarding art. 713, 714 and 727 of the Civil Code. The only peculiar case is when valorization occurs via EOR or similar non-conversion processes with permanent storage of the CO_2: this case is indeed very similar to CCS and therefore presents the same PR issues that we have identified in the case of CO_2 storage (cf. above), namely the lack of an unequivocal regulation concerning the property rights of the underground and the lack of clear liability rules concerning possible leakage in the near future of the CO_2 which is artificially stored in geological reservoirs.

These results are summarized in Table 8.1.

CCUS		*Public policies (PPs)*	*Property rights (PRs)*
Capture	*DAC*	No regulation.	Governed by art. 718 of the Civil Code.
	Capture from concentrated sources	Partial regulation when CO_2 is considered as air pollution (cf. OAPC). No regulation in any other cases.	Governed by art. 714 par. 1 of the Civil Code.
Transport		No regulation.	Governed by art. 714 par. 1 Civil Code.

Storage	Not explicitly mentioned. However, the aim of the climate policy provisions (see CO_2 Act) and the technology-blind approach to the mitigation measures outlined in both the CO_2 Act and the CO_2 Ordinanceare consistent with the possibility to resort to CCS applications to reduce GHG emissions.	Lack of an unequivocal regulation concerning the property rights of theunderground and of clear liability rules concerning possible leakage in the near future of the CO_2 stored. These legislative gaps could deter companiesfrom developing CCS projects in Switzerland.
Utilization	Analogous to the storage case. However, the CO_2 Ordinance requirement that emission reductions must be "verifiable and quantifiable" favors CCS over CCU.	PR in the majority of the utilization processes based on chattel ownership of the CO_2 and its possible transfer (see e.g. art. 713, 714 and 727 of the CivilCode). Only exception is when valorization occurs via EOR or similar non-conversion processes with permanent storage of the CO_2: this case presents the same PR issues identifiedin the case of storage.

Table 8.1: Identification of the main legislative gaps concerning the current PPs and PRs related to the processes of capture, transport, storage and utilization of CO_2.

8.2.5 CONCLUSIVE REMARKS

As it is discussed in this analysis, current PPs in the environmental and energy sectors never explicitly mention CCUS but many provisions of the CO_2 Act and the CO_2 Ordinance can be applied to CCS as well. The case of CCU is a bit more complicated, since the existing provisions at the legislative or at the executive level do not explain how the emission savings coming from CCU projects must be calculated in such a way to be counted as emission reductions or compensations. Therefore, contrarily to our analysis of section 8.1 concerning the legal status of carbon dioxide, for what concerns the existing PPs we have to deal not so much with inconsistencies but rather with regulatory gaps, especially regarding DAC and transport of captured CO_2.

The PRs analysis identifies some ambiguities which are potentially damaging for the development of CCS in Switzerland, specifically the property rights of the underground which could impact the possible use of geological reservoirs for CO_2 storage. An important gap in connection with these PRs is the lack of liability rules about possible leakages of CO_2 stored in geological reservoirs. On the other hand, user rights and disposal rights, as presented in section 5.2.2 and 5.2.3, respectively, do not seem to present particular issues in a hypothetical CCUS context.

8.3 THE TYPOLOGY OF THE IRR OF CCUS

This analysis shows that the main inconsistencies affecting the current legislative and institutional framework of CCUS in Switzerland arise from the legal status of carbon dioxide as it can be identified from the provisions of the 1983 EPA, whereas PPs and PRs are mainly affected not so much by inconsistencies as by the fact that some pieces of legislation which should regulate parts of CCUS processes such as CO_2 transport or utilization are still either missing or largely inadequate.

Consequently, while we cannot affirm that the current IRR of CCUS is completely coherent, we would say that incoherence is mostly limited to the legal status of CO_2 and in a large part it is a direct consequence of the scarcity of specific provisions on CCUS. Actually, we believe that the number and the seriousness of these inconsistencies is relatively limited in light of the vastness of the topic. Hence, with reference to the scheme of Fig. 8.1, we believe that the IRR of CCUS is currently a *simple regime* due to the vast gaps in the regulations that a comprehensive policy of CCUS should have in order to be effective. Therefore, in our opinion, integrating the current pieces of legislation such as the EPA or the CO_2

Act would be the most consequential manner to solve the inconsistencies affecting the legal status of CO_2 and create an *integrated regime* of CCUS in Switzerland.

PART II: NEW POLICY PROPOSALS

In this part we lay on an ensemble of proposals for the establishment of a coherent, integrated IRR to frame the development of CCUS in Switzerland. Therefore, we suggest a number of legislative changes and additions to the existing laws and ordinances, particularly the CO_2 Act, in order to broaden the current climate policies by integrating CCUS in the instruments for climate change mitigation, alongside the more traditional policies of energy transition. Generally speaking, as already discussed in section 2.1, legislation which promotes CCUS development is in agreement with art. 73 (sustainable development and recycling of natural resources) and art. 74 (protection of the environment from nuisances) of the Swiss Constitution, see appendix A. We structure our proposals following for the most part the design of chapter 8, summarized in Table 8.1, namely a subdivision of CCUS in its main components: capture, transport, storage, utilization.

9 THE GENERAL FRAMEWORK

Before approaching the individual CCUS components, we need to discuss the modification of perspective that the introduction of CCUS in the climate change mitigation toolkit can bring to climate change policies in general. Most of these considerations are so general that they appertain certainly more to a context of international environmental agreements than to the federal level policy which is the main focus of this work. Nevertheless, they still concur, as we will see below, to define some elements of the legal status of carbon dioxide and the IRR of CCUS.

First of all, negative emissions technologies (NETs), or carbon dioxide removal (CDR) technologies (see appendix A), introduce for the first time the possibility, at least on a theoretical level, to actively reduce not just the *emissions*, but also the *concentration* of CO_2 in the Earth's atmosphere, with techniques other than reforestation and created by the same industrialized society responsible for anthropogenic climate change in the first place. Following the last official IPCC reports, more and more industrialized countries are actually adopting policies and resolutions to become "net-zero" with respect to carbon dioxide emissions, therefore ending their contributions to anthropogenic global warming, by e.g. the year 2045 or 2050. For these countries, the path after carbon-neutrality would then be for them to become net-negative, reinforcing even more the deployment of NETs since net-negativity implies the removal of carbon dioxide from the atmosphere, which renewable energies development and energy efficiency measures are unable to provide just by themselves. In this context, it would be more adequate to identify the climate mitigation targets not in degrees Celsius of temperature increase (at the international level) or in percent values of GHGs emissions reductions (at the national level), as we currently do, but e.g. in concentration of CO_2 in the Earth's atmosphere (see volume 1, appendix B for technical details). In this way, even after having reached carbon neutrality, it will be possible to have a target to bring the level of CO_2 in the atmosphere back to a level deemed safer for the sustainability of the Biosphere.

Ideally, this level should be taken to be equal to the pre-industrial level of concentration of CO_2 in the atmosphere of about 280 ppm; in this sense, NETs should be used to restore the natural condition existing before the onset of the Industrial Revolution and of the concomitant disruption of the Earth's climate. Hence, it is the amount of CO_2 added to the pre-industrial levels which is the reason for the labeling of CO_2 as an "air pollutant"[32]. Removing this additional amount of CO_2 through the NETs would therefore allow to revoke the status of "air pollutant" to the carbon dioxide in the atmosphere. Of course, the choice of 280 ppm, while probably the easiest to justify, is still ultimately a political one and it could be worth investigating whether other choices for the desired concentration value would make even more sense in taking into account the enormous changes that occurred since the Industrial Revolution in variables with an important influence on the climate such as forest areas or the world population.

In practice, at the current state of technological development and opportunities, it would be extremely difficult to achieve the 280 ppm scenario, even in a long period of time. As a simple term of comparison, the current EU's ambition for CO_2 storage by 2050 is 12 billion tonnes of carbon dioxide; at the same time the global carbon emissions in 2018 alone amounted to 36.8 billion tonnes of CO_2, i.e. more than three times the EU target fo CCS over the next 30 years. Useful forecasts for CCU potential are still difficult to get due to the complexity of the topic, however it is unlikely that CCU development, while still helpful as one of the instruments in the climate change mitigation toolkit, can be determinant in a sharp reduction of atmospheric carbon concentration to pre-industrial levels within this century (see IPCC 2018).

[32] *The anthropogenic emissions of CO_2 have caused the atmospheric concentration of CO_2 to increase since the Industrial Revolution (well above 280 ppm and up to the current 415 ppm, as of May 2019), thereby driving the anthropogenic greenhouse effect.*

More in general, we believe that, if the deployment of CCUS technologies will occur at the large scale which is needed to tackle anthropogenic climate change, this complex CCUS infrastructure would afterwards be at disposal for the international community to manage the greenhouse effect and therefore, within certain limits, the climate on Earth indirectly through the management of the concentration of CO_2 (and possibly other GHGs). Hence, in principle, this community could succeed in controlling in the long term the Earth's average temperature as if we were controlling the temperature in a greenhouse. This would obviously open the door to both very worrisome and very exciting perspectives, especially because, in order to work properly, this situation would strongly require the international agreement and cooperation of all the main nations since the global nature of the climate is influenced by a myriad of individual and collective phenomena at the most disparate levels. In this context, it would be crucial that a new system of international treaties for the sustainable management of the resource "climate" were carefully designed and put in place. However, a full investigation of this issue is far beyond the scope of the present work and will not be treated here.

10 THE NEW LEGAL STATUS OF CO_2

According to the argument reported above, a concentration of CO_2 ($C[CO_2]$) in the Earth's atmosphere well below the current concentration of about 415 ppm should in principle represent the ultimate long-term target of a consequential and comprehensive climate policy which includes CCUS. As discussed in chapter 9, a target of 280 ppm appears to be still beyond a realistic reach in the current situation, even if the concept of such a threshold, that we will name henceforth "climate threshold", is important to structure the legal status of carbon dioxide in a sensible way. Therefore, it seems natural that a correct identification of the legal status of CO_2 taking this target into account should discriminate between two situations: the situation in which the concentration of CO_2 is above $C^*[CO_2]$, and the situation in which such concentration is equal to (or below) $C^*[CO_2]$, where $C^*[CO_2] \ll C^{today}[CO_2]$ represents the climate threshold for atmospheric carbon dioxide concentration. Such a threshold is taken to be equal either to 280 ppm or to a higher value, more realistically attainable, to be further determined both on a scientific and on a policy ground but in any case consistent with the (broad) objective stated in art. 2 of *UNFCCC* 1992 of a "stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". For sake of simplicity, we will take $C^*[CO_2] = 280$ ppm in the remaining of this chapter.

10.1 THE CASE IN WHICH $C[CO_2] > C^*[CO_2]$

In this section we will refer to the analysis of chapter 2, summarized in Table 2.1, to show how it is possible to modify the existing legal status of CO_2 in Switzerland in order to get to a legal status which is better suited to a policy scenario which deals with climate change mitigation and includes CCUS applications, looking at the EU case as a benchmark whenever useful.

10.1.1 CO_2 AS A RESOURCE

We believe that carbon dioxide should be considered as a natural resource whenever it can be valorized by CCU processes, both *in potentia*, that is, when it is free in the atmosphere but could potentially be captured via DAC techniques (analogously e.g. to water, which is generally regarded as a natural resource even when it is not directly engaged by the economic-productive system), and when it has been captured for a subsequent valorization.

The issue associated with a future increasing exploitation of the natural resource "carbon dioxide" (which would be extracted from the atmosphere in order to be valorized in different CCU processes) would be the risk of the depletion of the CO_2 in the atmosphere, which could theoretically decrease even below the 280 ppm of concentration which were recorded immediately before the Industrial Revolution as a consequence of an over-exploitation by human activities at a rhythm faster than the rhythm of renewal of the resource. Furthermore, the protection of carbon dioxide in the atmosphere from over-exploitation does not just protect CO_2 as a resource, but also as an essential element of the biological and ecosystemical equilibrium on Earth.

We would therefore need to introduce a legal definition of "natural resource", on the same foot as the definitions of "waste" (see art. 7 par. 6 *EPA* 1983) and "air pollution" (see art. 7 par. 3 *EPA* 1983).

Unfortunately, the Swiss legislation does not currently propose any definition of "resource". However, as reported in chapter 1, such a concept is implicitly at the basis of the fundamental principle of sustainable development in Switzerland, i.e. art. 73 *Federal Constitution* 1999, which reads: "the Confederation and the Cantons shall endeavour to achieve a balanced and sustainable relationship between nature and its capacity to renew itself and the demands placed on it by the population". Therefore, any future legal definition of "natural resource" should be largely inspired by this provision. In our opinion, a very good possible definition has been proposed by T. Largey, as "a material or immaterial element of the natural environment on which user rights may be exercised in order to benefit from ecosystem goods and services through a process of connection with a production system, while guaranteeing its conservation" (Largey 2017, p. 74), see section 1. This definition follows the same principle of sustainability as art. 73 of the Federal Constitution because it puts the accent on the balance between the human exploitation of the resource for goods and services on one side, and the need for a conservation and a renewal of the resource itself on the other.

Such a definition, or a similar one, could then integrate the list of definitions reported in art. 7 *EPA* 1983[33], since the principle of sustainability lies at the core of both this definition and the declared aim of the EPA, which "is intended to protect people, animals and plants, their biological communities and habitats against harmful effects or nuisances and to preserve the natural foundations of life sustainably, in particular biological diversity and the fertility of the soil" (art. 1 par. 1 *EPA* 1983).

The legal definition of natural resource could eventually lead to the creation of a "legal regime of resources", analogous to the legal regime of air pollutants described in *EPA* 1983 in art. 11 ff. and based on the legal definition of air pollution of art. 7 par. 3, or the legal regime of wastes described in art. 30 ff. and based on the legal definition of waste of art. 7 par. 6. However, the vastness of the concept of "resource" which covers a variety of elements such as water, forests or CO_2, suggests that it would be difficult to lay down the details of resource management directly in the EPA. It would rather be preferable to enunciate the general principles of the management of natural resources in a short number of articles in the

[33] *The EPA does not contain in its current form any general provisions regarding the preservation of natural resources such as water or forests. In fact, the legislator has preferred to leave these issues to specific laws such as the 1991 Waters Protection Act (WPA) (*Waters Protection Act *1991) and the Forest Act (ForA) (*Forest Act *1991) of the same year. For instance, art. 1 of the WPA states that the purpose of the Act is, among others, "to guarantee the supply and economic use of drinking water and water required for other purposes", "to preserve waters suitable as a habitat for fish", "to ensure the irrigation of agricultural land", or again "to ensure the natural functioning of the hydrological cycle", which are clear preservation purposes. In the same perspective, specific future provisions concerning the sustainable management and the preservation of the natural resource "carbon dioxide" should be put in a revision of the CO_2 Act.*

EPA, while putting more specific provisions into laws each of which dedicated to a natural resource in particular. For example, the specific provisions concerning the resource 'carbon dioxide' would be written in the CO_2 Act.

We will not focus here on the explicit form that this legal regime of resources could take in general, since it is beyond the scope of the present work which is dedicated specifically to CCUS. However, it is clear that an essential piece of this legal regime would be the protection of the resource against excessive exploitation and depletion when it puts in danger its natural capacity of renewal. We will present in detail in the next sections our proposals for the new provisions concerning the management of the resource 'carbon dioxide' in form of amendments of the CO_2 Act.

10.1.2 CO_2 AS AN AIR POLLUTANT

As we have discussed in chapter 2, we believe that the definition of "air pollution" contained in art. 7 sec. 3 EPA can directly apply to CO_2, which therefore assumes the status of 'air pollutant' in the atmosphere when $C[CO_2] > C^*[CO_2]$.

The 1983 EPA is the cornerstone of Swiss environmental law and regulates several environmental sectors in general terms. Even if ambient pollution control is one of its main domains, however, this Act has not been so far directly used as a source for climate action, which has been instead pushed through the CO_2 Act. The main reason for this is that the EPA was designed to deal with potentially dangerous *local* concentration levels of pollutants, whereas the danger of carbon dioxide is caused by its *global* concentration levels in the Earth's atmosphere.

Despite this, we believe that a certain number of provisions of the EPA are broad enough to be applicable to CO_2 as well. For instance, art. 11 and art. 12 of the EPA introduce the principle of emission limit values (ELVs) for air pollutants (as well as for noise, vibrations and radiation)[34], which are also used in the CO_2 Act to reduce carbon emissions from passenger

[34] *The actual ELVs are set out in the OAPC.*

cars, vans and articulated vehicles (see art. 10 *CO_2 Act* 2011). Moreover, art. 13 and art. 14 of the EPA bring out the principle of ambient limit values (ALVs) for air pollution, and since CO_2 can be considered as an air pollutant this principle can also be applied to CO_2, which in practice means that the Federal Council would be legitimated by art. 13 of the EPA to impose an ALV on the CO_2 concentration in the Earth's atmosphere, hence, an ALV which would be global and not local as the ones currently present in the OAPC. It would be natural to take this ALV to be 280 ppm, but this limit could actually be reached, if ever, only in the very long term. In the meantime, it would probably be more appropriate for the Federal Council to distinguish between different ALVs, each lower than the previous one, to reach at different moments in the future. It could also be interesting to introduce an absolute ALV never to be exceeded, which on the conceptual level would roughly correspond to the superior limit in the average increase in temperature of 1.5°C or 2°C set in the Paris Agreement. Other ALVs could correspond for instance to the targets to be reached in ten years or in fifty years. However, it is clear that these ALVs would be meaningless at a national level unless they were agreed upon in an international forum as well.

In general, if carbon dioxide is considered as an air pollutant, then it is subject to the legal regime of pollutants outlined in art. 11 ff. EPA, including:

- *prevention measures*, that is, air pollution must be "limited by measures taken at their source (limitation of emissions)" (art. 11 sec. 1 EPA) and more strictly so if "the effects are found or expected to be harmful [...], taking account of the existing level of environmental pollution" (art. 11 sec. 3 EPA). CCU and CCS technologies can contribute to eliminate, or at least strongly reduce, tailpipe emissions from various plants and installations. Art. 12 sec. b EPA further establishes that such limitations of emissions can be issued, among other things, by "regulations on construction and equipment", which could include for instance requirements to incorporate CCU or CCS technologies in the design of new industrial plants, or demands to retrofit existing installations with CCU or CCS technologies;

- *precautionary measures*, that is, "irrespective of the existing environmental pollution, [...] emissions are limited as much as technology and operating conditions allow, provided that this is economically acceptable" (art. 11 sec. 2 EPA). This provision puts in principle an upper limit on the financial burden which can be borne by the target groups. The OAPC then provides a guideline of what "economically acceptable" actually means, by settling that "the assessment of the economic acceptability of emission limitations shall be based on an average, economically sound enterprise in the relevant sector. If a particular sector contains widely differing classes of enterprises, the assessment shall be based on an average enterprise of the relevant class" (art. 4 sec. 3 OAPC). Therefore, in order to be able to apply this rule to CCS and CCU projects as well, it will be essential to perform an accurate and comprehensive techno-economic assessment (in the Swiss context) of the net cost associated with the installation of a CCS or a CCU project to the technical devices of an average enterprise of a certain economic sector.

An important issue is whether these ALVs should be established in a law or in the ordinance. While the ALVs for the traditional air pollutants are currently set in the OAPC

10.1.3 CO_2 AS A WASTE

The most important issue to solve when considering the status of CO_2 as a waste comes from its characterization as a "movable object" in Swiss civil law, therefore, as we have written in section 2, "the carbon dioxide stored before being released into the atmosphere is considered as waste, whereas the CO_2 which passes through a chimney before being directly emitted is not". This problem can be solved for instance by adopting the definition of waste given in the EU Waste Directive, according to which waste is "any substance or object which the holder discards or intends or is required to discard" (art. 3 par. 1 *Directive 2008/98/EC* 2008). Hence, we propose to amend the Swiss definition of waste given in art. 7 par. 6 of the EPA by simply substituting the expression “any movable material” with the expression “any substance or (movable) object”.

As a result, carbon dioxide would be considered as a waste, in a coherent way, whenever it is of anthropic origin and its destination is not the valorization, but rather the storage or the release into the atmosphere. In this last case, however, once it has been released in the atmosphere and mixes with other molecules of CO_2 of various origin, it can no longer be distinguished from them, therefore the status of “waste” is lost and it becomes an air pollutant and a (potential) resource. Instead, when the CO_2 of anthropic origin is injected in underground geological reservoirs, it remains separated from carbon dioxide of different origin and therefore it is still considered as waste.

In the case of DACCS (Direct Air Carbon Capture and Storage), CO_2 is captured from the atmosphere regardless of its origin, either natural or anthropogenic, at which point its legal status is defined by its destination: thus, if the goal of the capture is permanent storage in a deep geological reservoir, it constitutes waste according to the definition, since it is actually a substance “which the holder discards or intends [...] to discard”.

Waste is subject to the “legal regime of waste” outlined in art. 30 ff. of the EPA, especially to its three core principles which are the following:

- the production of waste should be avoided wherever possible;
- waste must be recovered (i.e. valorized) wherever possible;
- waste must be disposed of in an environmentally compatible way and, insofar as this is possible and reasonable, within Switzerland.

This can provide some fundamental guidelines for the management and disposal of CO_2, both in the case of storage of carbon dioxide from DAC and in the case of tailpipe emissions, which are consistent with the perspective offered by CCUS and other, more traditional, climate policies. In detail, the first principle (avoidance of production of CO_2 through fossil fuels combustion whenever possible) epitomizes energy efficiency and energy conservation, the second one is best exemplified by CCU and the third one advocates for an environmentally safe storage of CO_2. Although the main concern of the legal regime of waste as outlined in art. 30 ff. of the EPA is clearly the management and disposal of more traditional forms of waste such as municipal solid waste or hazardous waste, more unusual forms of waste such as anthropogenic CO_2 are covered by art. 30g *Handling of other forms of waste*, which states that "the Federal Council may enact regulations [...] on handling of other forms of waste, if environmentally compatible disposal is not guaranteed".

10.2 THE CASE IN WHICH $C[CO_2] \leq C^*[CO_2]$

In this situation, we assume that worldwide climate policies to tackle the anthropogenic (or enhanced) greenhouse effect have been successful in lowering the levels of CO_2 in the atmosphere to $C[CO_2] = C^*[CO_2]$. It is clear that an analogous target of reduction in atmospheric concentration should be set for the other anthropogenic GHGs as well, such as methane (CH_4) or nitrous oxide (N_2O). Pre-industrial levels of methane and nitrous oxide (conceptually analogous to the reference level of 280 ppm for carbon dioxide) were around 800 ppb and 260 ppb, respectively, as it is shown in Fig. 10.1.

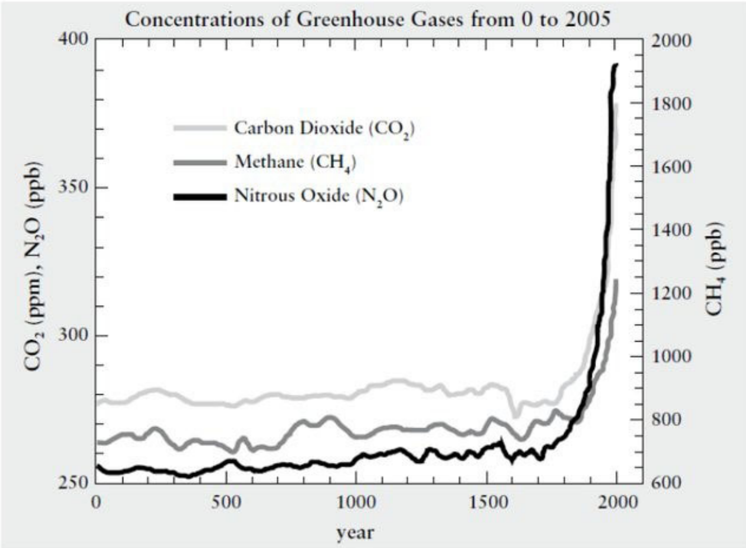

Figure 10.1: Atmospheric concentration of CO_2, CH_4 and N_2O, from the year 0 to the year 2005.
Source: Moumen et al. 2016.

10.2.1 CO_2 AS A RESOURCE

When the concentration of carbon dioxide matches pre-industrial levels, the anthropogenic perturbation of the Earth's atmosphere with regard to CO_2 concentration vanishes, hence CO_2 can no longer be considered as an air pollutant[35]. Instead, it is a resource in an even broader sense than when it is valorized by CCU processes, since its concentration is not anymore the result of anthropogenic emissions but is mainly regulated by photosynthetic organisms and geological phenomena, as it already was the case before the Industrial Revolution in the 18th century.

Ideally, at this stage a circular (or quasi-circular) carbon economy should have been implemented as a result of large-scale deployment of CCU as

[35] *Although this argument is actually conceptually valid only when we take* $C^*[CO_2] = 280$ *ppm, it could be made valid for a different value of* $C^*[CO_2]$ *on a policy ground, albeit not entirely on a scientific one.*

well as CCS. In this manner, the anthropogenic carbon cycle can complement and support the natural carbon cycle in regulating the levels of CO_2 in the atmosphere[36]. Therefore, while the current model of industrial society is the cause of the ongoing climate deregulation, the new model of industrial society should be explicitly created to solve it by boosting the role of carbon recycling and negative emissions in the global carbon cycle. However, if we hypothesize that in presence of over-exploitation of CO_2 its concentration in the atmosphere would fall well below the threshold of 280 ppm, the resulting scarcity of the resource CO_2 would enormously boost the importance of its role in both the natural biological processes such as photosynthesis (which are fundamental for the ecosystem equilibrium and the sustenance of life on Earth) and as a feedstock for CCU processes. This could have consequences both at a national and international level. The appropriation of atmospheric carbon dioxide could become much more strictly regulated. A tax could be also imposed on its withdrawal from the atmosphere in order to protect this resource from depletion. In such a situation, contrary to what happens today, energy-intensive plants and installations would probably be encouraged to "produce and spread" carbon dioxide while CCU projects would be strictly monitored or even reduced.

Despite this situation seeming unlikely (even prospectively) at the present time due to the energetic balance of the chemical reactions involving CO_2 favoring in general the burning of CO_2 over its valorization or storage, it is worth to examine this case in order to get a broader theoretical perspective of the legal status of CO_2 and the possible attached public policies.

10.2.2 CO_2 AS AN AIR POLLUTANT

The definition of air pollution reported in art. 7 par. 3 of the EPA reads, as we already know, that "air pollution means modification of the natural

[36] *While CCU is paramount in the creation of a quasi-circular carbon economy, CCS would be needed, in this perspective, to compensate those carbon emissions that we do not know how to bring down to zero.*

condition of the air, in particular, through smoke, soot, dust, gases, aerosols, steams, odours or waste heat”. If we consider $C[CO_2] \sim C^*[CO_2]$ to be the “natural” condition of the air for what concerns CO_2 levels, when $C[CO_2] \sim C^*[CO_2]$ it is clear that, if the amount of carbon emissions is not high enough to modify carbon concentration in a relatively short period of time (as opposed to the current situation) or if a quasi-circular economy is put in place to recycle (most of the) anthropogenic carbon emissions and hence to ensure that there is no progressive accumulation of CO_2 in the atmosphere, CO_2 does not constitute an air pollutant. This is certainly the main difference with respect to the case in which $C[CO_2] > C^*[CO_2]$ that we have analyzed before. A notable consequence of this fact would be that the “polluter pays” principle would obviously no longer be applicable to equipment emitting carbon dioxide. Indeed, such installations could even be encouraged to ‘replenish’ the atmosphere of the resource “carbon dioxide” in course of depletion, see section 10.2.1.

10.2.3 CO_2 AS A WASTE

It is evident that anthropogenic emissions of carbon dioxide in the atmosphere would no longer be considered harmful, as far as the greenhouse effect is concerned, if $C[CO_2] \leq C^*[CO_2]$. However, the EU-inspired definition of waste that we proposed above as a replacement of the current one given in art. 7 par. 6 of the EPA, “any substance or (movable) object which the holder discards or intends or is required to discard”, does apply even in this case, since the potential harmfulness of the waste does not enter its definition. Therefore, anthropogenic emissions of carbon dioxide are still a waste up to the moment of their spread in the atmosphere, when they become indistinguishable from the other molecules of CO_2. Carbon dioxide which is stored in the underground as a result of CCS projects is also, clearly, still a waste.

10.3 CONCLUSIVE REMARKS

Table 10.1 summarizes the main points of our proposal for a new legal status of carbon dioxide. It is clear that the main difference with respect to the current situation, which was summarized previously in Table 2.1 for both Switzerland and the EU, are the following:

- the dependence of the status of CO_2 on the actual concentration of carbon dioxide in the Earth's atmosphere, taking $C[CO_2] \sim C^*[CO_2]$ as the threshold value;
- a proposal for a definition of "natural resource", to be added to *EPA* 1983, possibly accompanied by a new "legal regime of resources";
- the fact that carbon dioxide in the atmosphere is regarded as an air pollutant only if $C[CO_2] > C^*[CO_2]$;
- a slightly different definition of "waste" which allows to decouple it from the status of "movable object".

Legal status of CO_2	*Definition (proposal)*	$C[CO_2] > C^*[CO_2]$	$C[CO_2] \leq C^*[CO_2]$
Resource	"A natural resource is a material or immaterial element of the natural environment on which user rights may be exercised in order to benefitfrom ecosystemgoods and services through a process of connection with a production system, while guaranteeing its conservation" (cf. Largey 2017)	CO_2 is an overabundant resource whenever it can be valorized by CCU processes,both *in potentia*, thatis, when it is free inthe atmosphere butcould potentially be captured via DAC techniques, and whenit has been capturedfor a subsequent valorization. CO_2 is subject to a "legal regime of resources".	CO_2 is a resource in danger of depletion, therefore strictly monitored. The importance of its ecosystemical role is particularly enhanced.CO_2 is subject toa "legal regime ofresources".
Air pollutant	"Air pollution means modification of the natural condition of the air, in particular, through smoke, soot, dust, gases, aerosols, steams, odours or waste heat" (art. 7 par. 3 EPA)	Atmospheric $CO_2$is an air pollutant, therefore subject to the legal regime of air pollutants (see art. 11 ff. EPA).	Atmospheric CO_2 is not an air pollutant.
Waste	"Waste is any substance or (movable) object which the holder discards or intends oris required to discard"(cf. art. 7 par. 6 EPA)	Anthropic CO_2 emissions up tothe moment of their spread in the atmosphere and CO_2 stored underground constitute waste, therefore are subject to the legal regime of wastes (see art. 30 ff. EPA).	Anthropic CO_2 emissions up to the moment of their spread in the atmosphere and CO_2 stored underground constitute waste, therefore are subject to the legal regime of wastes (see art. 30 ff. EPA).

Table 10.1: Proposal for a legal status of CO_2 which better suits the current environmental issues and the prospective development of CCUS.

11 CARBON CAPTURE, THE FIRST PHASE OF CCS AND CCU

As we can see e.g. from Table 8.1, DAC is currently not regulated whereas capture of carbon dioxide from concentrated sources is only partially regulated. Most of the rules governing carbon capture will be actually developed and discussed in the next chapters, i.e. in the broader context of CCS and CCU, which of course include carbon capture as the first fundamental operation. In this chapter we focus on filling the regulatory gaps in the IRR of CCUS concerning the CO_2 capture which have been discussed in section 8.2.

11.1 PUBLIC POLICIES

One should first check whether the provision of art. 6 par. 1 OAPC, which states that "emissions shall be captured as fully and as close to the source as possible and shall be removed in such a way as to prevent excessive ambient air pollution levels", should be modified or expanded in the perspective of the development of an integrated and consistent CCUS policy. We need to examine this issue in the light of the new legal status of carbon dioxide explained in chapter 10, as well as under the hypothesis that the climate threshold $C^*[CO_2]$ is taken into account in the legislation and that a circular economy of CO_2 is partly implemented in the future. We believe that this OAPC provision actually suits well this context, taking implicitly into account the climate threshold to suggest that:

- in the case in which $C[CO_2] > C^*[CO_2]$ and atmospheric carbon dioxide is an air pollutant, the capture and sequestration or the capture and utilization of CO_2 should naturally be encouraged by the public authorities;
- in the case in which $C[CO_2] \leq C^*[CO_2]$, atmospheric carbon dioxide would cease to be an air pollutant to become solely a resource, therefore automatically this OAPC provision would not apply in this

regime since it only targets air pollutants. This is consistent with the fact that in this situation CO_2 depletion would become an issue, therefore carbon capture in the context of CCUS should be much more strictly regulated.

If we wanted to have a resourceful approach to CO_2 capture at the same hierarchical level of this OAPC provision, we should:

- firstly, expand the Environmental Protection Act (EPA) in such a way to include a legal regime of resources, analogous in scope to the legal regime of waste outlined in art. 30 ff. of the EPA;
- secondly, amend the OAPC in such a way to include a set of provisions related to this legal regime of resources which distinguish the approach to the exploitation of a resource (such as in CO_2 capture and utilization) on the basis of the (relative) abundance of the resource itself, namely, favoring the valorization of the resource in case of overabundance of such a resource and its conservation otherwise.

11.1.1 DIRECT AIR CAPTURE

The regulation of direct air capture (DAC) is partially dependent on the subsequent path of the captured CO_2, whether storage or utilization, therefore many policy provisions potentially related to DAC will be discussed in the next sections dedicated to CCS and CCU.

In any case, in the hypothesis that the climate threshold of $C[CO_2] \sim 280$ ppm is introduced in the legislation and that a fully circular economy of CO_2 is implemented in the future, NETs would play a fundamental role in reducing carbon concentration in the Earth's atmosphere.

In the case in which $C[CO_2] > 280$ ppm, atmospheric carbon dioxide is an air pollutant, therefore the capture and sequestration or the capture and utilization of CO_2 should naturally be encouraged by the public authorities, for instance through the grant of subsidies. On the other hand, if NETs deployment is so important to bring $C[CO_2]$ down to $C[CO_2] \sim 280$ ppm or less, atmospheric carbon dioxide would cease to be an air pollutant to become solely a resource and, since CO_2 depletion would become an issue, DAC would likely be much more strictly regulated, in order to reduce the depletion of atmospheric CO_2.

11.2 PROPERTY RIGHTS

As we saw in section 8.2, the PRs which concern the capture of CO_2 are already sufficiently regulated by the norms of the Civil Code.

12 CCS

As we can see from Table 8.1, CCS is never explicitly mentioned in any of the Swiss laws and the ordinances governing the domains in which these technologies are supposed to have the greatest impact, such as climate mitigation policy. Nevertheless, a certain number of important provisions which are already in place are broad enough to be possibly also applied to CCS. This fact has allowed us, in part I, to identify a prospective IRR of CCUS in the existing legal provisions. The IRR analysis has then revealed the flaws and the gaps of these provisions and the urgent need for the coherent design of an official CCUS policy embedded in the ongoing climate policy.

Explicit mention of CCS in the Swiss legislation is made necessary by the need to address directly the most compelling issues facing its development. In the following, we are going to discuss how specific CCS provisions could be introduced in order to accelerate CCS deployment. Given the vastness of the topic, we will focus on the realistic (and current) case in which we are above the climate threshold, $C[CO_2] > 280$ ppm (see chapter 10), since the other situation is purely speculative at the present time.

12.1 PUBLIC POLICIES

The public policies which can affect the development of CCS facilities are examined in detail in the following pages. After a discussion of the legislation which should be amended to introduce a regulation of the phases of carbon transport and carbon storage, we propose a series of policy proposals in a vast number of sectors (regulation of CO_2 emissions, public subsidies, energy policy, etc.) aimed at encouraging the use of "carbon capture and storage" technologies.

12.1.1 STANDARDS FOR THE TRANSPORT AND STORAGE OF CO_2

After the phase of capture, that we have discussed in chapter 1[37], we now analyze the phases of transport and storage of CO_2.

Transport of CO_2

As we have seen in volume 1, chapter 3, transport of captured carbon dioxide can occur in four ways: pipelines, motor trucks, ships and rail, but essentially pipelines constitute the dominant mode of transport (Serpa et al. 2011).

There are no specific public policies governing the transport of carbon dioxide (see section 8.2.2), for example from the site of capture to a proper storage site, or even in district heating and cooling networks, as proposed in Henchoz et al. 2016. In fact, both the 1963 Pipeline Transport Facilities Act (*Federal Act on Pipeline Transport Facilities* 1963) and the 2000 Ordinance on Pipeline Transport Facilities (*Ordinance on Pipeline Transport Facilities* 2000) only apply to pipes used to transport mineral oil, natural gas or any other liquid or gaseous thermal or motor fuel. However, it would be relatively straightforward to amend this Act and this Ordinance in order to include carbon dioxide among the substances regulated and eventually special provisions concerning CO_2 since, from an engineering perspective, CO_2 pipelines, both onshore and offshore, are constructed in the same manner as hydrocarbon pipelines. Art. 1 of the Pipeline Transport Facilities Act would therefore read[38]: *"This law applies to pipes used to transport mineral oil, natural gas or any other fuel or liquid or gaseous fuel designated by the Federal Council, as well as to installations such as pumps and tanks used for operation of these pipes (collectively called hereinafter "installations").* ***It also applies to pipelines designed to transport CO_2 in relation to different possible***

[37] *Transport of carbon dioxide through pipelines is primarily associated with CO_2 transmission from the point of capture to suitable underground storage sites, and therefore with CCS, although it can be used to support CCU operations as well.*
[38] *The modification to the article is in bold font.*

aims, such as its transmission from the point of production or capture to a dedicated storage or utilization site".

The Ordinance on Pipeline Transport Facilities should then be amended in order to include the requirements of appropriate regulations and standards that the design of a CO_2 pipeline should meet "in terms of: pressure (wall thickness, over-pressure protection systems), resistance to degradation (internal due to, e.g., corrosion and external due to environmental conditions), protection from damage (e.g., burying the line), appropriate monitoring facilities and safety systems, and location considerations" (Serpa et al. 2011). A certain number of industry recognized standards and regulatory requirements specifically applicable to CO_2 transport through pipelines already exist. For instance, the DNV-RP-J202 standard is a guideline initiated by a joint industry project[39] with the goal to adapt existing pipeline standards to the special case of the transmission of carbon dioxide. This standard aims to provide criteria "for the development, design, construction, testing, operation and maintenance of steel pipelines" (Serpa et al. 2011), by taking into account technical discrepancies between the transmission of large amounts of CO_2 and of hydrocarbons through pipelines (Det Norske Veritas 2010). It is worth noticing that while in the U. S. CO_2 pipelines are subject to diversified local, state, and federal regulatory surveillance and there are minimum safety standards set up by the Department of Transportation, no comparable regulations for CO_2 pipelines exist in Europe.

Storage of CO2

When CO_2 is injected and stored in the deep underground space, it is considered as a waste, see section 10. Therefore, as we have already seen, in this case the legal regime of waste outlined in art. 30 ff. of the EPA ("Avoidance and disposal of waste") applies. However, the provisions of the EPA related to waste disposal and those of the correspondent Ordinance, the Waste Ordinance (ADWO) of 4 December 2015 (*Waste*

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[39] *This project is named CO_2 PIPETRANS and includes companies such as ArcelorMittal, BP, Chevron, Dong Energy, Gassco, Gassnova, ILF, Petrobras, Shell, Statoilhydro and Vattenfall.*

Ordinance 2015), deal with waste in the traditional sense. As a consequence, they do not contain specific provisions addressing the peculiar nature of the disposal of captured CO_2 and the environmental threats (leakage in the atmosphere, induced seismicity) associated with it. Hence, we believe that a list of essential provisions to regulate the injection of CO_2 in geological layers and the monitoring of the storage site should be included in the legislation.

These provisions could be inspired by the European law: for instance, the Directive 2009/31/EC of 23 April 2009, or "CCS Directive", provides a legal framework for the geological storage of CO_2 in a way which is "safe for the environment". Its scope is to reduce the risk of CO_2 leakage or damage to public health or the environment and to prevent any harmful effect on safety transport network or storage sites. It also allows for injection of CO_2 into saline aquifers for the purpose of geological storage. However, the CCS Directive is a *minimum requirement Directive*, hence the details of its implementation are the competence of EU Member States. Such details could be inspired by the specialized literature on this topic (Benson et al. 2005; IPCC 2006; Jewell and Senior 2012), including the CCS protocols and standards already existing, such as the *CSA Z741 - Geological storage of carbon dioxide* standard. The environmental impact assessment for CCS projects could also be inspired by the provisions contained in Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011, or "Environmental Impact Assessment (EIA) Directive", see section 5.1.2.

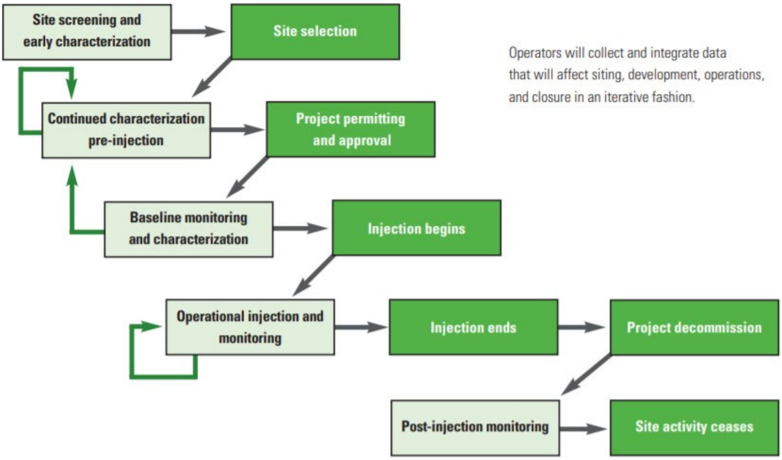

Figure 12.1: The different phases in the planning (light green boxes) and execution (dark green boxes) of a CO_2 storage project chain.
Source: WRI 2008.

The Waste Ordinance should therefore be amended to include an additional section, "Geological storage of CO_2", devoted to a regulatory framework for the injection of CO_2 in geological reservoirs and the management of the storage complex[40]. More specifically, it should regulate all the technical phases of planning, execution and monitoring of a CO_2 storage project, as shown in Fig. 12.1.

More precisely, this section should provide (WRI 2008):

- the norms for the assessment of the technical feasibility and the storage capacity of a sequestration site, including the conditions for the delivery of an exploration permit which would allow a short-term

[40] *In order to broaden the scope of this provision, it would be appropriate to include other GHGs too, not just carbon dioxide, among the gases which in principle could possibly be stored, see e.g. WRI 2008. It is however worth noticing that some provisions dealing with the storage of some of such gases already exist, albeit for purposes other than climate change mitigation, such as the* Ordinance on Compulsory Storage of Natural Gas *2017.*

geological survey and would possibly lead to a *site selection* for CO_2 storage;

- the procedures for *project permitting and approval*, regulating the drilling of any new injection and monitoring wells;
- the rules surrounding the delivery of an injection license, i.e. a certificate to permit CO_2 *injection* for other than evaluative reasons;
- the procedures for operational monitoring of the storage site, which is important to determine whether there are leakages of CO_2 in the atmosphere: individual wells may be temporarily or permanently plugged and abandoned throughout operations, but a site will close only after injection has ceased;
- following site closure and *project decommission*, there could be a period of *post-injection monitoring*, during which the storage site is assessed periodically to demonstrate that the project does not constitutes a danger for human health or the environment;
- once *site activity ceases*, the storage site could be managed by the government or an institution established for that purpose.

The London Protocol

The London Protocol[41] is an international agreement, adopted on 7 November 1996, to prevent pollution of the marine environment by dumping of wastes and other matter in the sea. Its Article 6 states that "Contracting Parties shall not allow the export of wastes and other matter to other countries for dumping or incineration at sea". During a meeting in October 2009, a Resolution was adopted for an amendment to Article 6 exempting export of CO_2 for storage purposes under the seabed from this restriction (IEA 2011; IOGP 2019). The 2009 Amendment adds the following paragraph to Article 6:

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[41] *More exactly, the "1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972".*

“2 Notwithstanding paragraph 1, the export of carbon dioxide streams for disposal in accordance with Annex 1 may occur, provided that an agreement or arrangement has been entered into by the countries concerned. Such an agreement or arrangement shall include:

1. *confirmation and allocation of permitting responsibilities between the exporting and receiving countries, consistent with the provisions of this Protocol and other applicable international law; and*
2. *in the case of export to non-contracting parties, provisions at a minimum equivalent to those contained in this Protocol, including those relating to the issuance of permits and permit conditions for complying with the provisions of Annex 2, to ensure that the agreement or arrangement does not derogate from the obligations of contracting parties under this Protocol to protect and preserve the marine environment.*

A Contracting Party entering into such an agreement or arrangement shall notify it to the Organization. ”

However, the entry into force of the Amendment requires two-thirds (34 out of 50) of Contracting Parties to ratify it. As of April 2020, only six countries have ratified and Switzerland is not among them. Therefore, in order to allow for the cross-border transport of CO_2 for the purpose of offshore storage, the Confederation should ratify the 2009 amendment of Article 6; in the meantime, Switzerland could support proposed temporary solutions, including preliminary entry into force among the current ratifying parties (IOGP 2019).

12.1.2 FEDERAL REGULATIONS OF EMISSIONS

The federal regulations of carbon emissions currently in place are established in the CO_2 Act and in the corresponding CO_2 Ordinance.

Generally speaking, we can distinguish two main kinds of regulations:

- regulations which aim at decreasing carbon emissions without specifying the technology to be used to reach the reduction target. The main example in Switzerland is obviously given in art. 3 par. 1 of the CO_2 Act, which reads: "Domestic GHG emissions must be reduced overall by 20 per cent as compared with 1990 levels, by 2020. The Federal Council may set sector-specific interim targets";

- regulations which require the use of a specific technology to reduce emissions. For example, a mandatory condition for the approval of the Gorgon project, a natural gas project in Australia, was the injection of at least 80% of the carbon dioxide released by the gas processing operations into the Dupuy formation (Global CCS Institute 2019). Another example, albeit a bit less restrictive from a legal perspective, is given in the Directive 2009/31/EC, or "CCS Directive", which states that EU Member States should ensure that the operators of combustion plants with a power of 300 MW or more, reserve sufficient space for the equipment required for capturing and compressing CO_2 (see section 5.1.2).

In general, it is clear that the imposition, at the level of a law or an ordinance, of a specific technology such as CCS to obtain a certain amount of reduction in carbon emissions could become problematic in case it gives rise to a political resistance from early opponents of CCS or from supporters of alternative emission-reducing technologies. Moreover, there is the concrete risk that such an imposition would prevent, at least in certain situations, the choice of other emission reduction options which are economically more viable.

Besides, the margin of uncertainty in relation to the future development of CCS in Switzerland is currently too high at this stage and it would make such a measure unrealistic. In general, the Swiss legislator appears to be wary of such rigid policy measures and prefer to leave to the private actors the choice of the specific technological instrument through which attain the desired emission reduction: in fact, the CO_2 Act and the CO_2 Ordinance, in their current versions, do not impose any specific technology to any target group as an emission-reducing measure. In future revisions of the Act or the Ordinance, we believe that it would be politically feasible to eventually introduce a technology-specific reduction goal only in situations for which there are no viable alternatives[42], a principle which is along the lines of the provision contained in the EU "CCS Directive" mentioned above. We will see an example of such a situation later when discussing the energy sector and in particular the case in which natural gas power plants would be set to replace the existing nuclear power plants in Switzerland which are scheduled to close once they reach their end-of-life, following the entry into force of the 2016 Energy Act.

We believe that the federal regulations of CCS should be contained in a new version of the CO_2 Act and the CO_2 Ordinance in the first place. This choice would emphasize the role of CCS technologies as an instrument for a net reduction of carbon dioxide emissions in its own right and on the same level of priority as renewable energy projects or energy efficiency measures. A separate Act for CCS (or CCUS) alone would instead reinforce an image of CCS and CCUS as disconnected from the other climate change mitigation methods.

More broadly, it would be useful to introduce already in the declaration of the aim of the CO_2 Act (art. 1 par. 1), next to the reference to the *reduction of GHG emissions*, a reference to *negative emissions* and, if needed, a definition of negative emissions as well, to be inserted in the list of definitions of art. 2 of the Act. This would allow not only to introduce the most adequate conceptual framework to deal with CCS, but also to shift the main paradigm of the CO_2 Act away from the sole mitigation effort towards the attempt to block and reverse climate change, in line with the philosophy of the "climate threshold" $C^*[CO_2]$ introduced above. The long-term goal would hence be to reduce carbon dioxide concentration in the Earth's atmosphere, as discussed in section 9.

[42] *As in the Australian example of the Gorgon natural gas project reported above, it could be possible for the government to impose a particular emission-reducing technology not by law but by passing specific agreements with some private companies in distinct cases.*

Art. 1 par. 1 of the CO_2 Act would therefore read[43]: *"This Act is intended (a) to reduce greenhouse gas emissions and in particular CO_2 emissions that are attributable to the use of fossil fuels (thermal and motor fuels) as energy sources,* ***and (b) to remove CO_2 from the atmosphere and store it in a way as permanent as possible,*** *with the aim of contributing to limiting the global rise in temperature to* ***well below 2 degrees Celsius above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 degrees Celsius above pre- industrial levels***[44]*"*.

Art. 2 of the CO_2 Act would then be expanded in the following way:

"Art. 2 - Definitions

[...]

CO_2 capture and storage, or CO_2 capture and sequestration, techniques (CCS techniques) are processes designated to separate (capture), condition, compress and transport a relatively pure stream of CO_2 either from industrial and energy-related sources, or from the ambient air, to a storage location for long-term isolation from the atmosphere. *"*

Finally, art. 7 of the CO_2 Act states that "the Federal Council or the competent department issues documents attesting reductions in GHG emissions achieved voluntarily in Switzerland" and that "it specifies the extent to which these attestations are considered equivalent to emission allowances or emission reduction certificates". This provision could be amended to introduce the concept of "negative emissions" and therefore of "reductions in GHG concentrations" alongside the more traditional "reductions in GHG emissions". This would allow to expand the recognition of CCS technologies, alongside with a few CCU applications with permanent storage of carbon dioxide, in particular concerning some processes with direct air capture (DAC), for the delivery of this kind of attestations which could eventually be considered equivalent to emission

43 In the following, all the modifications to a legal provision will be in bold font.
44 This modification takes into account the framework of the new version of the CO_2 Act, i.e. the Paris Agreement, specifically the formulation of the main goal of the Agreement as outlined in art. 2 par. 1 sec. a.

allowances. Consequently, they could possibly be traded on the market of ETS allowances, once the (currently too small) Swiss ETS will be coupled with the much larger EU ETS, see the discussion below. By establishing a certified exchange market for stored CO_2, this provision may participate in the establishment of a CO_2 storage market, similar to the recycling business of CO_2.

Concerning the CO_2 Ordinance, it states that emission reduction certificates are not issued for emission reductions that were achieved through projects for biological CO_2 sequestration or geological CO_2 capture and sequestration (see annex 2 art. 1 let. b and annex 3 let. b, cf. art. 36 par. 3 let. c), as already seen in chapter 5. These provisions should be eliminated in the perspective of a full integration of CCS projects in the ETS.

Art. 22 par. 1 of the CO_2 Act submits fossil-thermal power plants to the obligation to fully compensate for the CO_2 emissions caused[45]. In the perspective of CCUS development, we propose to modify this article as follows:

*"Section 2 - **Compensation in the case of Fossil-Fuel Thermal Power Plants**; Art. 22 - Principle*

[1] Fossil-fuel thermal power plants (power plants) may be constructed and operated only if their operators provide the Confederation with a commitment:

a. ***1. to capture and permanently store the CO_2 emissions caused, either in geological reservoirs or in carbon-containing products that meet the requirements of art. 2a[46], or***

2. *to compensate in full for the CO_2 emissions caused; and*

[45] A step further, in order to expand the possibilities for climate mitigation supported by this provision, could be to include some non-fossil-fuel-based, CO_2-emitting thermal power plants (for example, biogas power plants) in the group of power stations targeted by this provision.

[46] 9 Art. 2a is a new article that we propose afterwards in section 13.1.1 when discussing CCU.

b. to operate the power plant according to the current state of the art. The Federal Council specifies the minimum overall efficiency level that must be guaranteed.

[2] No more than 50 per cent of the CO_2 emissions may be compensated for through emission reduction certificates.

[3] The Federal Council may take account of investments in renewable energies, ***CO_2 capture and storage (CCS) or CO_2 capture and utilization (CCU)*** *in Switzerland as compensation measures.*

[...]"

Art. 83 of the CO_2 Ordinance lists the possible compensation measures for carbon emissions from fossil-thermal power plants. We have already proposed to eliminate from the CO_2 Ordinance the provisions excluding emission reductions achieved through CCS projects from the issue of emission reduction certificates and attestations for domestic emission reductions (see above). Through a modification of this article we could even explicitly add CCS to the permissible compensation measures from fossil-thermal power plants, as following:

"Chapter 6 - Compensation of CO_2 Emissions from Fossil-Thermal Power Plants; Art. 83 - Permissible compensation measures

[1] The following are permissible to meet a compensation obligation:

a. domestic emission-reduction projects and programmes self-implemented by the power plant operator that meet the requirements of Articles 5 and 5a;

b. investment in installations for the domestic production of heat or electricity using renewable energy sources that meet the requirements of Article 5;

c. investment in CCS and CCU domestic projects that meet the requirements of Articles 5 and 5a;

d. *the replacement of existing fossil-fuel heat sources with heat produced and directly decoupled by the power plant;*

e. *the surrender of attestations for domestic emission reductions;*

f. *the surrender of emission reduction certificates.*

[...]"

12.1.3 CARBON PRICING

A complementary approach to placing a value on emissions reduction through state regulations of emissions, including ETS, is to introduce some forms of price on carbon emissions. Carbon pricing currently occurs in the form of the carbon levy or the ETS, see chapter 5. As we already said, the introduction of a high carbon price would be able to increase the cost-effectiveness and application scales of CCS technologies in the market, given the relatively high cost of these technologies. In section 5.1.4 we already saw that the cost of CCS per tonne of CO_2 avoided varies greatly in relation to the specific capture technology used to capture CO_2 and to the industry whose installations are retrofitted with CCS. A recent, comprehensive review of the assessments of the cost of different CCS technologies in the existing literature also concluded that "costs for the majority of technologies throughout industries were found to range from US$ 20-120 [per tonne of CO_2 avoided, *ed*.] though with large ranges found, leading to a great deal of uncertainty over the true costs of implementing CCS within the sector" (Leeson et al. 2017).

In the larger context of the achievement of the temperature goal of the Paris Agreement of "well below 2 degrees Celsius", the World Bank in 2017 recommended to establish the carbon price in a range of at least US$40–80/t CO_2 by 2020 and US$50–100/t CO_2 by 2030. For CCS, this recommended price range is similar to the one found in Leeson et al. 2017, and although today the most expensive CCS applications would still remain economically unattractive even if such prices were attained by most countries, the specialized literature shows that significant reductions in capture capital costs are expected in the near future (*The Shand CCS Feasibility Study* 2018)[47].

In Switzerland, as it is shown in Fig. 5.2, while the amount of the carbon levy exceeds the price range recommended by the World Bank, the carbon price which results from the Swiss ETS is regularly much lower than even the lower limit of this range. For instance, during the auction of the ETS allowances organized in November 2017, the hammer price attained 7.50 Swiss francs per allowance, corresponding to less than US$ 7.50. Actually, today the vast majority of companies do not pay even this very low price for their emissions, since around 95% of the allowances are allocated free of charge and only the remaining 5% are auctioned (*Dispatch on the Amendment of the CO_2 Act* 2017). Indeed, according to art. 19, par. 2 of the CO_2 Act, allowances are granted free of charge to the extent that the emissions covered by these allowances are necessary for efficient operation in terms of GHG emissions (see also FOEN 2018b, p. 22). Another problem is caused by the fact that, because of the limited size of its market, in Switzerland the allowances are actually not traded between the participants in the scheme, instead the transactions are carried out directly and bilaterally between the few operators of installations and the possible intermediaries: therefore, the Swiss ETS is not a "true" emissions trading scheme. It is clear that such a high proportion of free allowances and the absence of the trade of allowances are both symptoms of a partially dysfunctional system, making eventually the administration of such a complex and tortuous mechanism, created in principle for the auction and the trade of allowances, quite unpractical.

[47] *As a matter of fact, more than 20 years ago a CCS project in Norway was already made economically attractive by a high carbon price. Indeed, the carbon tax introduced in Norway in 1991 has been very successful in providing with incentive the development of the Sleipner CCS project, which started in 1996. At US$ 17/t CO_2, the cost of injecting and storing CO_2 for the Sleipner project was much less than the US$ 50/t CO_2 tax penalty at the time for CO_2 vented to the atmosphere. This was complemented by a commercial need to separate the CO_2 from natural gas to meet market requirements and provided with an incentive to invest in CCS. The current level of the tax is higher than the level when it was introduced, making the business case for CCS at Sleipner even stronger (Furre et al. 2017; Global CCS Institute 2019).*

This fact is recognized as an issue for the Swiss climate policy in general (*Dispatch on the Amendment of the CO_2 Act* 2017; Wuthrich 2017), but it can affect in particular the future development of CCS since it waters down the carbon price signal, thereby reducing the impact of the relatively high amount (in international comparison) of the carbon levy, which today is of 94 Swiss francs per tonne of CO_2.

In conclusion, *in order to use and strengthen the carbon pricing system with the goal of encouraging CCS development, the Confederation needs to bring the average cost of carbon emissions, in the ETS sector as well, up to at least US$ 50/t CO_2*. In case this price tag were still not sufficiently high to make some CCUS projects viable from a financial point of view, the Confederation should consider handing additional funding over these kinds of projects, see section 12.1.4 below.

Different options may be considered to increase the carbon price in the ETS sector:

- the Federal Council could for example change the values of the benchmarks and adaptation factors reported in Annex 9 of the CO_2 Ordinance which, according to art. 46 par. 1 of the Ordinance, constitute the basis on which the Federal Office for the Environment (FOEN) calculates the quantity of emission allowances to be allocated free of charge annually to ETS companies. These modifications should be meant to decrease drastically the amount of allowances which are handed out free of charge in the ETS;
- the amount of allowances (either auctioned or allocated for free) is too high in general for the small Swiss market, so high, actually, that for ETS participants there is virtually no pressure to reduce their emissions. Hence, the 'cap' of the ETS (the total amount of annual allowances) needs to be recalculated and severely reduced. In this manner, with fewer allowances in circulation, not only their price would go up in the auctions, but also the ETS participants that do not get enough allowances to cover the totality of their emissions must either strongly decrease their emissions (i.e. through CCS projects) or

pay the CO_2 levy, which is in principle higher, on those emissions which are not covered;

- a minimum carbon pricing (a "carbon price floor") could be introduced in the ETS if the government promised to purchase any amount of allowances for a given price. This would allow to increase the average price of CO_2 emissions in the ETS, and therefore to make carbon pricing a strong driver to decrease these emissions;
- lastly, the future coupling of the Swiss ETS with the much larger EU ETS[48] will automatically enlarge the number of participants in the market of emission allowances and will therefore finally allow to implement a real emission trading in Switzerland as well.

12.1.4 CAPITAL GRANTS AND LOANS FROM THE GOVERNMENT

To deploy CCS at the rate necessary to meet the climate change targets, financial investment must increase by orders of magnitude. To achieve this, not only banks have a critical role in providing debt financing for investments by project developers: governments can also play a very important role in funding CCS projects (Global CCS Institute 2019).

It is well understood that bringing new energy technologies to market is challenging because they are beset by the so-called "technology valley of death" where financing is difficult to obtain for innovations that, although technically proven, are not yet deployed at commercial scale (Murphy, L.M. and Edwards, P. L. 2003). This describes the current situation of CCS technologies in the marketplace well. Grant funding helps to address this serious issue, first by rewarding early investments for the knowledge they create that can be used by future project developers, and second by making investments more attractive to private sector investors, helping to

[48] *The Swiss ETS covers currently just 54 energy intensive installations responsible for 10% of the Switzerland's GHG emissions (*Dispatch on the Amendment of the CO_2 Act *2017). Conversely, the EU ETS covers approximately 11,000 energy intensive installations in power generation and manufacturing industry sectors responsible for about 45% of the EU's GHG emissions (see section 5.1.2 and European Commission 2016).*

increase investment, to bring down the cost of finance and to build confidence in the technology (Global CCS Institute 2019).

There are several kinds of subsidies that the public authorities may hand out to contribute to the funding of CCS projects:

- the government could finance *loan guarantees* for CCUS applications. In particular, the Technology Fund established under art. 35 of the CO_2 Act to promote innovative technologies that reduce GHG emissions and the consumption of resources, support the use of renewable energy and increase energy efficiency, could be used to lower the financial hurdle to companies that are trying to develop CCS projects (and CCU projects as well) in Switzerland. A specific annual fraction of the total amount of the Fund could also be reserved explicitly for this scope. Hence, art. 35 par. 3 of the CO_2 Act would read: *"The money in the Technology Fund is used by the Confederation to guarantee loans to companies for developing and marketing equipment and processes to: a. reduce greenhouse gas emissions* ***and concentration, notably through the use of CCS and CCU techniques****; b. facilitate the use of renewable energies; or c. encourage the economical use of natural resources"*. Alternatively, a special fund could be created *ex novo* (e.g. with an amendment to the CO_2 Act) to finance loans for the deployment of CCS technologies. Such a provision would improve the chances for CCS applications to carve out its own space in the market;

- the government could also finance *grant support*, a kind of subsidy which goes a step further than a loan since the recipient does not have to pay it back. This method has already been used to fund the construction of transport and storage networks, to address the cross-chain risk[49] that capture plant developers are exposed to. This is the approach that has been adopted i.e. for the construction of Alberta

[49] *Cross-chain risks are risks related to failures of one element of a project chain affecting another one. For instance, in the case of CCS, the unavailability of a carbon capture infrastructure would have ramifications down the CCS chain for the (available) CO_2 transport and storage parts of the same CCS project.*

Carbon Trunk Line in Western Canada, which has received CAN$558 millions from the Alberta and Canadian governments for the CAN$1.2 billions project: the 240 km pipeline connects CO_2 emitters in Alberta's industrial centres with underground oil reservoirs in central and southern Alberta for use in EOR (Global CCS Institute 2019). In Switzerland, similarly, this kind of subsidy could be used to fund particularly important and massive projects, too risky for private companies alone to carry out, such as the construction of a network of pipelines expressly dedicated to the transport of captured carbon dioxide from the clusters of concentrated industrial sources which are located e.g. in the Swiss Plateau to injection sites for underground storage in Switzerland, if possible, or otherwise elsewhere in Europe (such as, for example, in the North Sea basin, which has a huge storage capacity and whose geology is already very well understood, see of Commons of the U.K. 2006).

Certain forms of subsidy could also be connected with the carbon pricing methods (cf. 12.1.3):

- *ETS*: analogously to what was shown in section 5.1.2 for the case of the EU ETS, the subsidy could take the form of allowances not required to be surrendered with respect to emissions which are captured and stored;
- *CO_2 levy*: alternatively, if an energy or industrial plant is subject to the CO_2 levy and it reduces its CO_2 emissions by capturing carbon dioxide from its exhaust gas and storing it permanently in geological reservoirs, according to the discussion conducted in section 12.1.2, the Confederation would have to recognize the emission reduction caused by the installation of the CCS facility. As a consequence, the company should either have to pay a lesser amount of the CO_2 levy, or have the CO_2 levy partially or totally refunded, in proportion to the emission savings originated by the use of the CCS facility;
- by the same logic, it could be conceivable for the Confederation to award to a company which captures CO_2 directly from the atmosphere

and store it permanently in geological reservoirs (direct air carbon capture and storage, or DACCS) the same amount of money[50] as the tax savings of the emitting installation in the previous example, since the net environmental gain is equivalent in the two cases. This could be called a *negative carbon tax*, a name reminiscent of the "negative income tax" proposed, among others, by M. Friedman in the 1960s (see e.g. Friedman 2002).

12.1.5 ENERGY POLICY

As we discussed in volume 1, chapter 4, CCS can play a role in supporting the federal energy policy as outlined in the 2016 Energy Act. Here we list the legal provisions that could be enacted, for each one of the three strategic objectives of the Act[51], to address the possible use of CCS technologies in this domain:

- in order to complement the *development of renewable energies*, CCS has a relevant role to play with biomass use in the sector of bioenergy with carbon capture and storage (BECCS, see volume 1, chapter 3), which would make the biomass use for energy production a sector with net negative carbon emissions. Although energy from biomass currently represents only a small fraction (4.4% in 2018, see Confédération Suisse 2019) of the total energy production in Switzerland, this could change based on the planned phase-out of nuclear energy (see also volume 1, chapter 4). In fact, the quota of national electricity production currently met by nuclear power could be replaced, at least in the short-to-medium term, not only by natural gas-fired power plants (cf. volume 1, chapter 4), but also by biomass power stations. BECCS could therefore be encouraged by measures under the CO_2 Act, for instance through public subsidies as those outlined before, as well as a specific mention of BECCS among the possible measures to reduce carbon concentration in the atmosphere.

[50] *At least on a theoretical level, since with two competitive pricing systems (the CO_2 levy and the ETS) the carbon price tag may vary.*

[51] *These three objectives are: the development of renewable energies, the increase of energy efficiency and the exit from nuclear energy, see volume 1, chapter 4.*

No provisions related to bioenergy production are currently present in the CO_2 Act. The new provision may therefore read: ***"Biomass power plants should be supplemented by CCS or CCU facilities whenever this is physically, technically and economically feasible, in agreement with the goals of this Act as expressed in art. 1 par. 1"***;

- *energy efficiency* is certainly reinforced by the possible use of excess renewable electricity to power CCS operations, therefore the provisions outlined in the previous discussion point apply here as well;
- as we already discussed in volume 1, chapter 4, the *de-commissioning of nuclear power plants* in Switzerland could potentially lead to replace these plants (at least partially) with natural gas power stations. In this case, in order to avoid the emission of large amounts of GHGs, it would be problematic for the owners of such installations to avoid fitting CCS facilities to such plants. The CO_2 Act already contains a provision requiring the operators of fossil-fuel thermal power plants to compensate in full for the CO_2 emissions caused (see section 2 of the CO_2 Act). As we already discussed in section 12.1.2, we believe that it should be possible for the public authorities to require not just a full compensation for the emissions caused, but even to avoid a certain amount of emissions outright through the installation of CCS facilities to the natural gas power plant[52], if feasible. This provision not only would be necessary to prevent a dramatic increase of carbon emissions in our energy system which would be at odds with the energy transition policies, but would also give a particularly important boost to the development of CCS facilities in Switzerland.

However, we should also notice a possible source of conflict between the Energy Act and the large-scale development of CCUS in Switzerland. In fact, art. 3 of the Energy Act outlines the goal of reducing energy and electricity consumption by the year 2035 by an amount equal to 43% and 13% of the 2000 level, respectively. On the other hand, CCUS facilities

[52] *CCS technologies can currently capture only a fraction of the carbon dioxide emissions from a fossil-fuel power plant.*

would require substantial amounts of energy to operate. The direct consequence of this fact would be that, if one chooses to include CCUS development to enlarge the number of climate change mitigation tools, in order to keep these targets the reduction in energy and electricity consumption should be even higher for end consumers in Switzerland.

In order to moderate or avoid this conflict, another approach would consist in either the redefinition of the targets or the introduction in the Energy Act of a provision excluding the power required for the operation of CCUS processes from the total energy and electricity savings outlined in art. 3.

12.1.6 SPATIAL PLANNING POLICY

As we saw in volume 1, chapter 3, the installation of CCS facilities requires the delivery of permits to build such facilities, such as installations for DAC or for CO_2 injection and storage. The essential provisions on delivery of building permits and on land use planning in Switzerland are currently enacted in the Spatial Planning Act (SPA) of 22 June 1979 (*Spatial Planning Act* 1979). A permit for a building or an installation can be granted only if the buildings and installations conform to the purpose of the land use zone and if the land is connected to infrastructure and utilities (cf. art. 22 SPA). No explicit mention of CCS or CCU facilities is made in the SPA and this lack of a strong legal basis could potentially hinder the construction of this kind of facilities in Switzerland.

Art. 8b of the SPA, which states that "the structure plan shall designate suitable areas and stretches of water that may be used to generate renewable energies", was introduced in 2016 with the scope to boost renewable energy development: we propose to create a similar provision to include CCS infrastructures. Therefore, we could introduce a new article which could read as follows:

"Art. 8c - Structure plan content in relation to CCS infrastructures

[1] The structure plan shall designate suitable areas that may be used to build CO_2 capture and storage (CCS) facilities, as well as the associated pipelines for CO_2 transportation wherever necessary, in agreement with the goals of the CO_2 Act.

[2] The designation of such areas depends on previous geological assessments to identify the storage capacity of possible CO_2 storage sites, as defined in the Waste Ordinance[53]."

Such a provision would prompt the public authorities responsible for land planning and land development to reserve in advance some suitable areas for CCS facilities in the land use planning. This would allow to integrate coherently such complex and delicate pieces of infrastructure with the surrounding environment, especially the residential areas, well before the actual construction starts. This is particularly important if we need to take into account the risks of opposition from residents of the neighbouring areas that some CCS projects may cause.

More in general, we believe that, because of the prospective large-scale development of CCS, in the future a comprehensive planning of the land use does not have to consider the potential uses of the surface land only, but does need to take into account the possible uses of the underground as well, in order to ensure a rational and sustainable use of the geological reservoirs.

12.2 PROPERTY RIGHTS

CO_2 storage suffers from a number of regulatory issues concerning property rights, see Table 8.1. In particular, we need to address the issue of property rights of the underground, where the captured CO_2 should be stored, as well as the lack of clear liability rules concerning possible leakage of CO_2 stored in reservoirs.

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[53] *See section 12.1.1.*

We saw in section 5.2 that the CO_2 injected and stored in geological layers is subject to the legal regime applicable to the underground, which is not exactly defined in the law but that, according to the current legal consensus, presumably corresponds to the monopolistic control of the cantonal authorities. We believe that it is necessary to clarify the issue in the perspective of a possible large scale development of storage options in Switzerland.

- First of all, we believe that it is necessary to add a new provision to the Constitution or to the Swiss Civil Code that would establish the nature of property rights of the deep underground. A simple amendment to an existing law[54], in our opinion, would not be the most appropriate choice, because of the difference in hierarchical level that in this case would exist between the law currently governing the private property of the underground space "to the extent determined by the owner's legitimate interest in exercising his or her ownership rights", which is art. 667 par. 1 of the Swiss Civil Code, and the law governing the property of deep underground space. According to the discussion conducted in section 5.2, both the Constitution and the Civil Code are appropriate to include an article about the deep underground, well below the thin layer just underneath the surface which is itself the object of art. 667 par. 1 of the Swiss Civil Code. For instance, the Constitution already contains provisions which specify the legal competences of the Confederation about water (art. 76) or about nuclear energy (art. 90).

Concerning the content of a legal provision on the property rights on deep underground space, we believe that it would be necessary to modify the current legal consensus and *attribute the monopolistic control of the underground not to the Cantons but to the Confederation*. There are multiple reasons for that. One reason is that, in the perspective of a large scale development of CO_2 storage in Switzerland, the underground areas of geological reservoirs such as the saline aquifers in the Swiss Molasse

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[54] *Which could be the SPA, if the principle of an "underground use planning" is incorporated into the Act.*

Basin typically trespass the cantonal borders (projected downwards into the underground). Hence, only the Confederation can deal with the issue related to carbon storage at the appropriate scale. Moreover, in the EU, geological reservoirs are owned by the States (WRI 2008), and since they may obviously trespass not only cantonal borders, but also national ones, it makes sense to align the Swiss legislation in this domain with the EU one.

In such a situation, the federal government could then lease CO_2 storage sites to private companies willing to invest in CCS projects. Concerning the open surface lands over the geological reservoirs, in Switzerland it is frequently owned by various public entities such as cantons and municipalities (Nahrath, Peter Knoepfel, et al. 2009). Therefore, the operators of a CO_2 storage project would need to work with different property owners in order to get legal access to both the surface area and the underground pore space (WRI 2008).

13 CCU

The current situation of CCU in the Swiss legislation is close to the one of CCS, i.e. CCU is never explicitly mentioned in any piece of legislation (see Table 8.1). Therefore, we aim at elaborating concrete proposals to promote the development of CCU technologies in both the PPs perspective and the PRs perspective, considering, as in section 12, only the present time situation, in which $C[CO_2] > 280$ ppm. Some proposals and instruments which have been presented in section 12 for CCS projects are also equally valid in the case of CCU.

13.1 PUBLIC POLICIES

As reported in section 8.2, the essential distinction between CCS and CCU for what concerns PPs lies in the fact that the reductions in carbon emissions due to the use of CCS technologies are in principle “verifiable and quantifiable”, which is requested by art. 5 par. 1 let. c sec. 1 of the CO_2 Ordinance, whereas those coming from the use of CCU technologies are rarely so. Indeed, with the exception of some specific processes bordering on CCS (such as enhanced oil recovery or carbon mineralization), the carbon dioxide which is captured and valorized in a useful product can be re-emitted in the atmosphere at the end of the product’s lifetime, see volume 1, chapters 2 and 3. In fact, the scope of CCU is to get to a “circular economy of carbon”, whose aim is to stabilize the level of carbon dioxide in the atmosphere, rather than to decrease this level (in a perspective of negative carbon emissions) as it is the case for CCS. However, even if most CCU technologies do not decrease the concentration of CO_2 in the Earth’s atmosphere in the long term, they still can reduce (or at least retard) carbon emissions compared with a benchmark “business as usual” situation in which CCU is not present.

Moreover, as already explained in volume 1, section 2.1, CCU processes would allow to replace, at least partially, the extraction and the utilization of fossil resources for the manufacture of some products, thereby addressing another important environmental issue, i.e. fossil resource depletion.

It is extremely difficult in general to calculate with precision the "emission savings" coming from the majority of CCU processes, whereas in the case of CCS the emission savings are represented by the amount of CO_2 which ends up being stored. This difficulty is due to the large variety of possible CCU technologies and the complexity of the parameters which are involved in the assessment of life cycle carbon emissions of a specific CCU process. For example, the carbon balance on the whole life cycle of a product created with a CCU process can be different according to the energy source which was used to power the process, e.g. renewable energy or fossil energy.

To overcome this issue that menaces to jeopardize the large-scale development of most CCU processes as instruments of the climate policies, some researchers and organizations are trying to define nevertheless a consistent, comprehensive and harmonized method to calculate and report emission savings from CCUS technologies, which would therefore become the "gold standard" adopted not only by the industry, but also in relation to climate policies at the international level. For example, the Global CO_2 Initiative is currently working on the establishment of a global, industry-standard *Techno-Economic Analysis and Life Cycle Analysis (TEA/LCA) Toolkit*, built upon existing LCA ISO standards and guidelines. This toolkit should ideally serve as the critical framework and foundation for the nascent CO_2 removal and utilization industry to analyze the technologies that may have the most impact and ability to succeed in meeting climate and commercial goals (Zimmerman et al. 2018).

Until the moment of the effective adoption of such a universal methodology for the calculation of life-cycle emissions and the consequent update of the IPCC Guidelines for National GHG Inventories to include CCU for a vast number of processes as a possible instrument for climate change mitigation, there will still be issues for the official recognition, at least at the international level, the role of a large part of CCU technologies in the achievement of the Paris Agreement targets.

However, this does not mean that CCU technologies may not be taken into account at all in the class of emissions-reducing options. As we saw in volume 1, section 3.4, we can distinguish two main categories of CCU processes:

- CCU processes in which the final product stores carbon for a period of time which can be considered as permanent with respect to the target of climate change mitigation in this century (conventionally, this period is taken to be at least a hundred years);
- CCU processes in which the final product releases the recycled CO_2 at the end of a life cycle generally spanning from some days to a few years.

Therefore, the processes which can be included in the first category (e.g., mineralization of CO_2) can effectively be considered as equivalent to CCS. Conversely, the processes in the second category need to be treated more carefully when considering their possible use as climate change mitigation techniques. Nevertheless, we believe that it is still possible to integrate them into the legal framework outlined in the CO_2 Act and the CO_2 Ordinance, with some changes.

13.1.1 FEDERAL REGULATIONS OF EMISSIONS

A proposal to include CCU as an emission-reduction strategy

In the **case of carbon capture from concentrated anthropogenic sources**, when a company, or a cluster of companies, decides to apply a certain CCU technology to (a part of) their manufacturing processes, that is, to capture CO_2 emitted by their own operations in order to use it, the resulting global carbon balance needs to be compared to the one of the baseline scenario without CCU. Whether the processes with CCU emit more or less GHGs than in the baseline case depends on a series of factors, for instance on whether or not the energy used to operate the additional

CCU processes is low-carbon. However, the carbon balance could be evaluated on a case by case basis, using the same rules currently employed by the FOEN to assess GHG emissions from companies subject to the CO_2 levy or to the ETS (art. 45 to 65 of the CO_2 Ordinance), to reduction obligations (art. 66 to 79), or to compensation of emissions (art. 80 to 85).

In case only one company is responsible for both the capture of CO_2 and its subsequent utilization, e.g. for the manufacture of a new product, the FOEN would be in charge of the assessment of the evolution of carbon emissions consequently to the introduction of CCU with respect to the baseline scenario. The boundaries of the system for this life cycle analysis would then be the same which would have been taken to evaluate the CO_2 emissions by the same installation without CCU, thereby making a comparison between the two scenarios, i.e. before and after the introduction of CCU, quite straightforward.

However, in most of the cases, at least two different companies would be involved in the addition of a CCU facility to the existing infrastructure: the first company (i.e., the CO_2 supplier) to supply the CO_2 emitted by its manufacturing processes, the second one (i.e., the CO_2 user) to use the captured CO_2 as a feedstock for its own products. In order to assess the change in the total amount of GHG emissions as result of the integration of the CCU process, the FOEN could hence compare the GHG emissions for the combination of the two (or more) companies involved in the CCU operation chain before and after the introduction of CCU.

We suggest to reward both the CO_2 supplier and the CO_2 user, in different ways, for the recycling of carbon dioxide through a set of policy and fiscal instruments. We choose not to reward the multiple companies involved in the CCU project as a single entity, even if this may complicate the design of the desired policy tools. Indeed, in such situations the various companies of the CCU project typically keep their different legal statuses separated. It is therefore important, in our opinion, that the distribution of taxes and subsidies reflects from the beginning the individual role played by the various companies in the project.

In the following discussion, we take these companies to be ETS companies for sake of simplicity, but the line of reasoning is analogous in case the companies were subject to a non-refunded payment of the CO_2 levy. Specifically:

- the CO_2 supplier would see its flue emissions decrease due to the carbon capture process; this would allow the company either to sell the surplus of its own ETS allowances to other ETS participants, or to reduce the number of allowances that the company needs to match its actual emissions. Moreover, the selling of the captured CO_2 could allow the CO_2 supplier to increase its revenue[55];
- if needed, the CO_2 user may be subsidized by the federal government in order to manage to sell the products manufactured with the captured carbon dioxide. This could be done by putting in place a system of specific CCU subsidies quite analogous to the "feed-in tariffs" introduced in Switzerland in 2008 as an instrument for the promotion of electricity generation from renewable energy sources (see e.g. Weibel 2011). These CCU subsidies would be paid directly to the CO_2 user as a fixed remuneration, to cover or, at least, reduce the difference which may exist between the production cost of the CCU-based product, and the market prize of that same product realized in a traditional way which does not involve CCU. This would guarantee the CO_2 user to be able to cover its production costs and would make it competitive on the marketplace.

While, according to our proposal, the payment of the CO_2 levy or the participation in the ETS would not be required by law in order for a company or a set of companies to be able to install CCU equipment to its or their manufacturing processes (only the approval of the project by the FOEN would be necessary), it is obvious that this system of benefits would fully deploy its effects only when coupled with the ETS-based economic gains, at least for what concerns the CO_2 supplier. However, the CCU subsidies discussed above would be available to any CO_2 users

[55] *Of course, as the scale of CCU development will increase, the price of CO_2 will drop.*

involved in a CCU project which is approved by the FOEN, even if they do not take part in the ETS.

In the **case of direct air carbon capture and utilization (DACCU)**, i.e. when a company decides to use CCU technology to capture CO_2 from the atmosphere, either to use it directly or to sell it to a manufacturing company for subsequent utilization, the framework presented above still applies. However, in the case of more than one company involved in such a project, the CO_2 supplier may see a *net negative emissions balance* due to the capture of carbon dioxide from the atmosphere, if the energy used to power its operations is sufficiently low-carbon in order not to offset the gains coming from the capture of CO_2 from ambient air. Such a company[56], which does not include manufacturing processes but would be only a CO_2 supplier extracting carbon dioxide from the atmosphere, would not be part of the ETS and therefore would not be able to sell the surplus of its own ETS allowances or to reduce the number of allowances that it needs to surrender in order to match its actual emissions. Hence, all of its revenue would come from the selling of the captured CO_2. A complement to this source of revenue could come, as already proposed in section 12.1.4 for the case of DACCS, by establishing a *negative carbon tax* proportional to the amount of negative emissions achieved via DAC and before the utilization phase, thereby rewarding them in a similar manner as CO_2 captured from concentrated anthropogenic sources (see also section 13.1.2 below).

The framework for the emissions assessment

In general, direct GHG emissions connected with the life cycle of CCU-based products can be divided in two main sectors:

1. emissions from the industrial installations, ranging from the traditional manufacturing plants to the CCU facilities, within the integrated cluster of the CCU companies, and
2. emissions from the end-of-life of CCU-based products,

[56] *A company of this kind would be ClimeWorks, for example.*

whereas the indirect emissions which are probably the easiest to take into account are:

3. emissions from energy facilities providing heat and power necessary for CCU operations.

Of course, indirect GHG emissions caused by the deployment of some CCU technologies may also be large. For instance, the production of biomass to be fed to integrated biorefineries in the context of BECCU (Bio-Energy with Carbon Capture and Utilization) for the production of various CCU-based industrial products such as a number of chemicals may provoke an increase in emissions from land-use change, which can be important but difficult to calculate with good accuracy. This hardship in dealing with indirect emissions from CCU in a scientifically grounded approach, together with the high number of variables which intervene in CCU processes and can therefore influence the amount of emission savings, explains the difficulty of coming up with a well-defined, universal method to calculate the full impact that CCU may have on climate change.

Electricity consumption by CCU processes is often regarded as one of the main issues of CCU, since such consumption is generally much higher than in a business-as-usual scenario or in a scenario in which equivalent emission cuts are obtained through CCS. For instance, in Gabrielli et al. 2020 a comparative analysis of three technology chains (CCU, CCS and biomass-based) to set up a carbon-neutral chemical industry in a world with net-zero CO_2 emissions is performed to show that the CCU scenario requires a power consumption 10 to 25 times higher than that of the other two pathways (without considering the electricity needed for heat production). It is clear that only a massive development of renewable energies worldwide could allow such a huge increase in power consumption to go without a dramatic worsening of anthropogenic climate change. Therefore, in our approach, it is important that the assessment of carbon emissions from the CCU projects submitted to the FOEN for approval incorporate not just the *direct emissions from* *operations at the CCU facilities* but also the *indirect emissions from energy consumption*[57].

Instead, we believe that we should not include end-of-life emissions from CCU-based products, since such emissions would occur even if the products were manufactured without resorting to CCU, therefore they would not matter when comparing the carbon balance of a industrial or energy project with and without CCU. Hence, in this framework, FOEN rules to evaluate end-of-life carbon emissions of CCU-based products would be the same as the ones existing for analogous goods produced without resorting to CCU. Consequently, the issue of the non-permanent storage of carbon dioxide in the final product can be avoided simply understanding CCU just as an alternative way to organize the industrial operations for the manufacture of a product which would otherwise be fabricated in more traditional ways, using fossil resources. *In conclusion, from our point of view, in CCU the focus lies not on carbon storage as in CCS, but rather in a "reorganization" of the manufacturing processes allowing a decrease of the overall carbon emissions in the integrated system with respect to the baseline scenario without CCU.*

As a consequence, in this framework, the requirement in art. 5 par. 1 sec. c of the CO_2 Ordinance that domestic emission-reduction programmes must be "verifiable and quantifiable" is compatible with CCU projects (cf. section 5.1.3), provided that the emissions caused by such projects are assessed, as stated before, (i) within the proper boundaries of the system delimited by the energy providers and the technical equipment of the CO_2 supplier(s) and the CO_2 user(s), while (ii) using the same rules that the FOEN employs to evaluate carbon emissions from any other emitting installation. In fact, as we have seen, the carbon balance in (i) can be

[57] *However, it is worth noticing that power consumption should not be the only criterion to take into account when dealing with CCU, there are other factors which play a role. For instance, the use of CO2 as a feedstock instead than oil for the manufacture of chemicals reduce fossil resource depletion. Furthermore, CCU has a more direct impact on atmospheric CO2 concentration, the main drive of climate change, than emission offsetting or compensation. Even if the latter is widely used as a climate change mitigation tool, in reality a compensation project does not erase the targeted carbon emissions of a certain company, which still occur even if they are nominally "compensated".*

calculated with good accuracy, while end-of-life emissions and indirect emissions other than those caused by the energy providers are much more controversial to evaluate.

Of course, the downside of this approach lies in the renunciation to reward the positive climate effects of CCU connected to a delay in the emission of carbon dioxide, which is released into the atmosphere at the end of its residence time in the product rather than as tailpipe emissions. However, given that the difficulty in estimating such delays accurately enough makes taking them into account particularly challenging (as discussed above), we believe that our approach allows to include a number of CCU processes among the possible instruments of the CO_2 Act to reduce GHG emissions in a coherent and functional manner.

In order to be eligible for FOEN approval, any CCU project should of course meet the basic requirement that the industrial processes emit less GHGs by unit of product over the whole life cycle after the installation of the CCU system than the industrial processes which were in place before the introduction of the CCU facility. The boundaries of the system to conduct such an assessment would include the technical equipment of the CO_2 supplier(s) and of the CO_2 user(s).

It is worth noticing that the actual *extent* of the cut in carbon emissions due to the installation of the CCU facility is automatically taken into account in this system by the nature of the ETS, which rewards bigger cuts in GHG emissions. On the other hand, while it is true that the incentives in the system of CCU subsidies are not proportional to the amount of carbon savings, it still recompenses the substitution of fossil resources with captured CO_2 for the manufacture of products, which is an important step in the direction of addressing the issue of anthropogenic climate change.

The actual legal provisions

In the following, we suggest in detail how to modify existing provisions of the CO_2 Ordinance in order to integrate and regulate the possible use of CCU technologies to achieve the federal climate targets under the CO_2 Act.

First, similarly to what has been proposed for CCS (cf. section 12.1.2), we could include a definition of CCU in art. 2 of the CO_2 Act, as well as a new article specifying the requirements that a CCU-based product needs to meet in order to be considered akin to permanent CO_2 storage (as in CCS) from a legal perspective:

"Art. 2 - Definitions

[...]

6 ***CO_2 capture and utilization techniques (CCU techniques) are processes designated to capture CO_2 either from industrial or energy-related sources or from the ambient air and convert it to a carbon-containing (C-containing) product, or CCU-based product, which can then be used to deliver a direct service to society."***

"(New) Art. 2a - Permanent storage in carbon-rich products
1 C-containing products which can safely store CO_2 for a duration of 100 years or longer may be considered akin to CCS techniques in regard to some scopes of the present Act, whenever explicitly stated.

2 The Federal Council specifies the list of such products."

We refer to the new art. 2a in the proposed new version of art. 22 par.1 of the CO_2 Act, where fossil-fuel thermal power plants are required to commit to capture and store their carbon emissions in a permanent manner, i.e. either through CCS or in the kind of CCU-based products described in art. 2a, see section 12.1.2.

The CO_2 Ordinance shall then be modified to include provisions about the aforementioned points. A first article would refer to the guidelines for a CCU application as well as for possible subsidies to the CO_2 user:

"(New) Chapter 4 - Carbon Capture and Utilization (CCU); (New) Art. 40

[1] One or more companies wishing to install and operate a CCU facility within their own manufacturing processes must follow the ensuing procedure:

a. it or they must submit an application to the FOEN following the guidelines contained in art. 6 par. 2;
b. the application should specifically detail the hypothetical evolution of greenhouse gases emissions from the industrial processes following the introduction of the CCU equipment. In order to be validated, the application should outlook emission reductions per unit of output with respect to the situation without CCU.

[2] In case the production cost of a product manufactured through CCU techniques exceeds the market prize of the same product realized in a more traditional way without CCU, the FOEN grants to the producer a subsidy aimed at covering, totally or partially, this difference. If no actual equivalent of the CCU-based product can be found in the market, the FOEN may consider a product with an analogous function.

[3] The FOEN determines which CCU-based products are eligible for these subsidies as well as the modality of distribution of the incentives. It also fixes their maximum amount, which is updated annually based on the evolution of the market prizes. "

A second article would then tell how CCU projects could play a role in the ETS:

"Section 2 - Emission Allowances and Emission Reduction Certificates;

[...] ***(New) Art. 51 - Carbon Capture and Utilization (CCU).***

The amount of CO_2 emissions from the producing installations of an ETS company which is captured and sold to another company to manufacture a CCU-based product can be subtracted from the total emissions which are covered by the emission allowances in possession of the ETS company."

Emission reduction certificates in the case of CCU

It is worth noticing that, in their current formulation, the CO_2 Act and the CO_2 Ordinance do not explicitly forbid to take into account emission reductions which were achieved through CCU techniques by issuing emission reduction certificates in the same way they forbid CCS, see section 12.1.2. Nonetheless, annex 2 art. 1 let. d of the CO_2 Ordinance limits the possible CCU techniques which can be taken into account for the issue of such certificates to the ones which obtain their emission reductions through at least one of the methods listed in this provision, e.g. the use of renewable energy. However, powering CCU operations with renewable energy sources is often essential in order to reduce carbon emissions with respect to a situation without CCU. Therefore, the limitations imposed by annex 2 art. 1 let. d of the CO_2 Ordinance eventually would not prevent to take into account most CCU processes for the issue of emission reduction certificates.

The main, possible controversial, issue could rather lay in the fact that emission reduction certificates are "internationally recognised tradable documents attesting to reductions in emissions achieved abroad" (art. 2 par. 4 of the CO_2 Act) and that emission reductions achieved abroad may be counted only "if they are attested to by an emission-reduction certificate of the United Nations Framework Convention on Climate Change (UNFCCC) of 9 May 1992" (art. 4 par. 2 let. a of the CO_2 Ordinance). Thus, emission reductions achieved abroad through a project involving the installation of a CCU facility would need to be validated by the UNFCCC, in particular under art. 6 par. 4 of the Paris Agreement which promotes sustainable development mechanisms. As we have already said in this section, our approach for the assessment of CCU project in relation to climate change mitigation conceives effective CCU techniques as a "reorganization" of traditional industrial and energy processes which can provide a reduction of their emissions per unit of output. We believe that this approach allows to quantify with the necessary accuracy emission savings resulting from the introduction of

CCU in the current industrial and energy framework[58]. Consequently, we believe that such CCU methods could in principle be validated by the UNFCCC through emission-reduction certificates. However, this is a very complicated issue and a comprehensive discussion is beyond the purpose of this work.

Attestations for domestic emission reductions in the case of CCU

Attestations for domestic emission reductions which, according to art. 7 of the CO_2 Act, can be considered equivalent to emission allowances or emission reduction certificates, could in principle already be issued for CCU projects which are effective in cutting emissions. The issue of such attestations occurs on the basis of art. 5 of the CO_2 Ordinance. In particular, this article specifies that such domestic emission reductions:

- "must be verifiable and quantifiable", which is what precisely occurs within our approach to assessment of CCU processes, as seen before; and
- "were not achieved by a company participating in the Emission Trading Scheme (ETS)", in order to avoid double-counting of the same emission reduction, i.e. by the ETS company and by the company applying for the attestation for domestic emission reductions at the same time.

Thus, the CO_2 Ordinance in its current formulation does not need to be modified in order to include CCU among the domestic emission reduction techniques which can be eligible for the issue of legally recognized attestations.

13.1.2 CARBON PRICING, CAPITAL GRANTS AND LOANS FROM THE GOVERNMENT

Once we have shown, in the previous section, that CCU may be considered as an instrument of the CO_2 Act to reduce carbon emissions

[58] *This approach runs up against a more conventional viewpoint that considers most CCU processes as non-permanent, or semi-permanent, storage methods, whose emission savings are thereby difficult or even impossible to estimate accurately.*

from industrial and energy processes, and we have illustrated in particular how this could be accomplished within the context of the ETS, it is straightforward to see that further interventions on carbon pricing mechanisms such as those discussed in section 12.1.3 for CCS could be easily extended to CCU as well. Indeed, the signal given by a higher *carbon price* would also encourage the development of CCU technologies.

For what concerns *capital grants and loans from the government*, we have already proposed in section 13.1.1 to subsidize CO_2 users by putting in place a system of remunerations to CCU companies to cover, totally or partially, the difference existing between the production cost and the actual market prize of the final product. Moreover, as we already said in section 12.1.4, a part of the Technology Fund established under art. 35 of the CO_2 Act could be used to promote not just CCS, but also CCU.

Different forms of subsidies connected with the carbon pricing methods, similarly to what we have already seen in section 12.1.4 for CCS, are also possible:

- *ETS and CO_2 levy*: as already discussed in section 13.1.1, the subsidy in this case takes the form of either ETS allowances not required to be surrendered, or a partial or total refund of the CO_2 levy, in respect of emissions which are captured at the tailpipe of the installations of the CO_2 supplier, for subsequent utilization;
- the *negative carbon tax* proposed for DACCS could be also applied to Direct Air Capture and Utilization (DACCU); hence, the Confederation should award a company which captures CO_2 directly from the atmosphere with the goal of its utilization with the same amount of money as the tax savings of the emitting installation in the previous example, since the net environmental gain is the same in the two cases.

13.1.3 ENERGY POLICY, INDUSTRIAL POLICY AND SPATIAL PLANNING POLICY

The proposals presented in section 12.1.5 concerning *energy policy* are valid for both CCS and CCU, therefore we refer to that section for the discussion about the possible ways to include CCUS in the federal energy policy system. In particular, the large increase in electricity production which would be required in case of a massive development of CCUS facilities would mainly be caused by CCU processes, as seen in section 13.1.1.

The possible inclusion of CCU in the *industrial policy* and in the federal *spatial planning policy* should occur around the concept of *eco-industrial parks (EIPs)*[59], that is, "industrial parks designed to improve the social, economic and environmental performance of their resident firms, including through the promotion of industrial symbiosis and green technologies delivering resource efficiency and resulting in competitive advantage, promoting climate-resilient industries and green value chains, as well as inclusive and sustainable business practices and socially responsible relations with surrounding communities" (see UNIDO 2019 and appendix A). It is therefore clear that CCU can play an important role in such EIPs, given its focus on recycling, the circular economy and climate change mitigation. Currently in Switzerland there are a few of these parks, such as the Basel Industrial Area Park (Klybeck, Rosental, St-Johann, Schweizerhalle), the park of the Chablais eco-industrial region, the Daval eco-industrial park, and some others (Massard et al. 2014). The main issue is that currently in Switzerland there is not an official industrial public policy at the federal level (cf. Pirmin 2011). Therefore, we believe that the introduction of the concept of CCU within the framework of the EIPs should occur in the context of the federal spatial planning policy.

First, the Confederation needs to establish a sectoral plan, in collaboration with the Cantons, specifically dedicated to the development of eco-

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[59] *Sometimes the expression "eco-innovation parks" is also employed.*

industrial parks and networks. Then, the Spatial Planning Act (SPA) should be modified by introducing a new article:

"(New) Art. 8d - Structure plan content in relation to eco-industrial parks and networks

1 'Eco-industrial parks and networks' designate areas where industrial activities are grouped and coordinated according to the principles of sustainable development.

2 Wherever possible, the structure plan shall designate suitable areas (i) to expand and connect existing industrial and energy installations, or (ii) to create new ones, in such a way to form eco-industrial parks and networks.

3 In particular, the structure plan shall consider the opportunity of integrating CO_2 capture and utilization (CCU) facilities to these parks and networks, in agreement with the goals of the CO_2 Act.

4 The designation of areas for eco-industrial parks and networks shall be conducted according to the guidelines established by the sectoral plan of the Confederation relative to the installation of such eco-industrial parks and networks. "

13.2 PROPERTY RIGHTS

As we have seen in Table 8.1, the property rights in the majority of the valorization processes of CO_2 are already regulated under provisions of the Swiss Civil Code, such as art. 713, 714 and 727. The only exception is given by processes like enhanced oil recovery (EOR) because, like CCS, they store permanently the captured CO_2 in geological reservoirs. The issue with the lack of an unambiguous regulation concerning the property rights of the deep underground space is the same as in the case of CCS, therefore the proposal for its solution will be the same which has been discussed in section 12.2.

14 CONCLUSIVE REMARKS ON PART II

In part II, we have presented a vast ensemble of new proposals to improve the current IRR (i.e., the IRR based on the existing legislation) which would govern a hypothetical large-scale development of CCUS in Switzerland.

In chapter 10 we have laid out specific proposals to redefine the legal status of carbon dioxide with the current Swiss legal instruments. In particular, we have seen that two different regimes should exist, one in which $C[CO_2] > C^*[CO_2]$, where e.g. $C^*[CO_2] \sim 280$ ppm and where carbon dioxide is an air pollutant in the atmosphere, and one in which $C[CO_2] \sim C^*[CO_2]$ and atmospheric carbon dioxide is not an air pollutant.

Then, after a short preamble in chapter 11 about the phase of CO_2 capture, in chapters 12 and 13 we have presented our policy proposals to amend a number of provisions such as the CO_2 Act, the Energy Act, or the Spatial Planning Act (SPA) in order to explicitly include CCUS in the respective public policies. These proposals are made with a minimalist approach in mind, to disrupt as little as possible of the existing legislative framework. For instance, no new act is introduced; instead, only existing acts are modified to integrate some CCUS-related provisions. We also notice that in our case the introduction of CCU in the legislation has been much less straightforward than that of CCS and is not as precise in rewarding emission savings, due to the vastness and complexity of the current landscape of CCU processes, of which we still have somehow a limited knowledge.

Table 14.1 summarizes the proposals for a coherent legislation governing CCUS in Switzerland that we have discussed in chapters 12 and 13.

	CCS	**CCU**
Standards for the transportand storage of CO_2	Transport: amend the Pipeline Transport Facilities Act and the Ordinance on Pipeline Transport Facilitiesto include special provisions concerning CO_2. Storage: amend the Waste Ordinance to include a section to regulate all the phases of planning, executing and monitoring a CO_2 storage project.	
Federal regulations of emissions	Amend the CO_2 Act to include (1) a definition of CCS, (2) a reference to the need for negative emissions, (3) the possibility for fossil-thermal power plants to use CCS and some CCU processes to meet their compensation obligations.	Amend the CO_2 Act to include the definition of CCU. Amend the CO_2 Ordinance to define the guidelines for an application to the FOEN about a CCU project and to grantsubsidies to CCU, and to define the role that CCU can play in the ETS.
Carbon pricing	Bring the average cost of carbon pollution in the ETS sector up to at least US$ 50/tCO_2, e.g. by (1) decreasing drastically the amount of allowances which are handed out free of charge in the ETS, by (2) introducing a "carbon price floor", or by (3) reducing the total amount of annual allowances.	
Capital grants and loans from the government	Amend the CO_2 Act to include CCS and CCU in the Technology Fund. Finance grants for specific CCS and CCU projects. Recognize emission reductions obtained through CCS and CCU in the ETS andin the CO_2 levy. Introduce a *negative carbon tax* for DACCS and DACCU.	
Energy policy	Amend the CO_2 Act with a provision to supplement biomass installations with CCS or CCU facilities whenever feasible.	
Spatial planning policy	Amend the SPA with a provision to boost the development of CCS infrastructures in thecontext of spatial planning.	Amend the SPA with a provision to boost the creation of eco-industrial parks in the context of spatial planning, including the integration of CCU facilities to them.
Property rights	Amend either the Constitution or the Civil Code to explicitly attribute the monopolistic control of the underground (in the context of CO_2 injection and storage or of some CCU processes such as EOR) not to the Cantons, but to the Confederation.	

Table 14.1. Summary of the main proposals of legislative changes to promote CCUS development in Switzerland.

CONCLUSIONS

Today we are assisting across the industrialized world to a surge of debates and proposals, both of a technical and a political nature, concerning the large-scale deployment of a wide array of technologies, which can be collectively referred to as carbon capture, utilization and storage (CCUS) technologies. The reason for this intensification in the public discourse is two-fold:

- on one hand, the sense of urgency related to anthropogenic climate change and the seemingly unstoppable growth of carbon dioxide concentration in the atmosphere has brought renovated attention to carbon capture and storage (CCS), which would theoretically allow to store vast amounts of CO_2 in underground reservoirs, as well as to some CCU methods such as carbon mineralization or enhanced oil recovery (EOR) that would also allow to permanently store carbon dioxide away from the atmosphere;
- on the other hand, the transition from a linear to a circular economy may be about to drive the biggest transformation in business since the Industrial Revolution through a radical departure from the traditional production and consumption models, and the recycling of carbon dioxide through CCU processes would be an important part of this circular economy in a perspective of sustainable development.

Although the western countries where the debate around CCUS is the strongest, and where also the policies have been the most receptive to such innovations, are countries such as the United States, Canada, Norway or the United Kingdom, rather than Switzerland, in recent times there have been some signals that a policy discussion about the role that CCUS technologies could possibly play in Switzerland's climate policy is increasingly sought in both the Federal Assembly and the Federal Council. For instance, in a parliamentary postulate titled *What might be the significance of negative CO_2 emissions for Switzerland's future climate policies?*, submitted to the Federal Council the 12 December

2018, the national councilor Adèle Thorens asked the Council to provide a report showing how much negative emissions, in the form of CCS or CCU, could be important for future climate policies in Switzerland (Thorens 2018). The answer of the Federal Council of the 20 February 2019 was the following: "The Intergovernmental Panel on Climate Change's special report on global warming of 1.5 degrees makes it clear that global net CO_2 emissions must be reduced to zero by mid-century. Emissions reduction measures must be complemented by negative emission technologies (NETs), which absorb CO_2 in the atmosphere and store it sustainably in natural and/or artificial wells. In this context, Switzerland also needs to address different aspects of NETs, such as potential uses, theoretical and achievable potentials, costs and risks, and governance issues" (Thorens 2018). And while "theoretical and achievable potentials, costs and risks" of NETs are issues which have been treated only marginally in this work because their technical nature requires a more thorough and specialized analysis, the potential uses and the issue of governance constitute the fundamental core of this Thesis. Indeed, as explained in detail in the Introduction, our analysis is based on the IRR approach (Gerber et al. 2009), which resorts to the intersection and mutual dependence of public policy and property-rights theory to show how these two dimensions have an impact on the governance of the CO_2, which has different implications if the CO_2 is, depending on its use and situation, a resource, a waste or an air pollutant. We have chosen a minimalist approach to the issue of the creation of a new IRR of carbon dioxide, that is, the creation of new legal provisions to govern the possible uses of CO_2 in CCUS processes, those same uses which in turn participate in the definition of the legal status and property rights of CO_2. Our IRR analysis has started with what is, to our knowledge, the first attempt of description of the IRR of carbon dioxide that exists at present in Switzerland and that would embed CCUS deployment if no further legislative action were taken (the "existing IRR", in short). The next steps have consisted in (1) the identification of the gaps and inconsistencies of the existing IRR with respect to the new uses of carbon dioxide given by CCUS, and in (2) the presentation of a number of proposals simply aimed at filling these gaps and correcting these inconsistencies, without passing through the creation of laws or ordinances ex novo, which would have consistently weighed down the procedure.

At the end of our analysis, we can answer the main research questions that we presented in the General Introduction:

- *"What are the main sources of CO_2 in Switzerland and in which economic sectors does the greatest potential for carbon recycling lie?"* - The main anthropogenic sources of CO_2 in Switzerland, from a CCUS perspective, have been explored in volume 1, chapter 4 and we have found that the largest potential for CCUS applications lies in the sectors of manufacturing industries and construction, as well as electricity and heat production, while smaller roles can be played by cement production, petroleum refining and incineration. However, as we already said, a much more thorough analysis is needed to quantify more exactly the emission savings which could be realized by applying CCUS technologies to these sectors;
- *"What are the most important existing public policies and legal provisions, in the current state of their formulation and implementation, which could regulate a hypothetical future development of a large-scale CCUS sector in Switzerland?"* - Themain existing public policies (PPs) and legal provisions which could regulate a future, hypothetical development of a large-scale CCUS sector in Switzerland (in the current state of their formulation and implementation) are the climate policy outlined in the CO_2 Act and in the CO_2 Ordinance, the environmental policy 'at large' outlined in the Environmental Protection Act (EPA) and the energy policy described in the Energy Act.

  Moreover, given the importance of property rights (PRs) in the development of the PPs related to CCUS, the Civil Code is also a piece of legislation that plays a fundamental role in elucidating the PRs connected with the uses of carbon dioxide;

- *"Which opportunities can be found within these provisions to encourage such a development?"* - The CO_2 Act and the CO_2 Ordinance contain provisions that allow CCS technologies, and some CCU technologies as well, to be considered, in principle, as emission reduction (or emission compensation) measures. Furthermore, the act of putting a price on carbon through the carbon levy and the Swiss ETS constitutes a financial incentive to the deployment of CCS and CCU facilities.

  The EPA plays an important role in the definition of the current legal status of CO_2. In particular, it allows to define it as an air pollutant under certain conditions and as a waste when stored. The EPA also provides a legal regime of air pollution and a legal regime of waste than would in principle apply to CO_2 with the corresponding status.

  The Civil Code in its current formulation can regulate almost every stage of carbon dioxide in the CCUS processes, with the exception of the storage since there are no clear provisions establishing the PRs of the deep underground space (see Table 8.1).

  Finally, the Energy Act contains provisions related to the penetration of renewables in the national energy mix, energy efficiency measures and the exit from nuclear power, that could indirectly promote CCUS development;

- *"Using the IRR conceptual approach, what can be said about the degree of coherence and integration of the provisions contained in the existing institutional and legal framework of CCUS?"* - The IRR analysis has shown in volume 2, chapter 8 that the IRR of CCUS is currently a simple regime because of the vast gaps in the regulations related to CCUS. Therefore, integrating the current pieces of legislation such as the EPA or the CO_2 Act would be the most effective and minimalist manner to solve the inconsistencies affecting the legal status of CO_2 and design an integrated regime of CCUS in the Swiss context;

- *"Which legislative changes are desirable and/or conceivable in order to create a coherent and integrated IRR of CCUS, following the remarks of the previous IRR analysis?"* - These legislative changes are outlined in volume 2, part II. For what concerns the legal status of CO_2, we have proposed to make it dependent on a "climate threshold", e.g. at the pre-industrial level of 280 ppm of concentration of CO_2 in the atmosphere, which would discriminate between two regimes in the new legal status of CO_2, according to whether the actual concentration of CO_2 in the atmosphere is higher or lower than the climate threshold: only in the first case atmospheric CO_2 would be an air pollutant.

  Finally, concerning the policy proposals to integrate the CO_2 Act, the Energy Act etc. to explicitly include CCUS, we refer to the quite long and detailed discussion contained in chapters 11, 12 and 13 and summarized in Table 14.1. Here we just recall that one of the most important differences between CCS and CCU - namely, that emission reductions can be easily and precisely calculated for CCS processes, not quite so for the most part of CCU technologies - is at the basis of the difficulty for CCU in general to be recognized as an instrument of emission savings in its own merit.

  We have proposed a pragmatic solution to this issue, namely that we choose to evaluate only the carbon emissions related to the actual manufacture of the CCU-based product and not the whole life cycle emissions of the product. Therefore, we regard the CCU process as a possibly emission-saving alternative to a more conventional industrial manufacture of the same product without CCU, hence we are interested in a comparison between the two manufacturing processes within the same boundaries, on a case-by-case basis. As a result, the carbon balance would take into account energy-related and manufacture-related emissions but not the end-of-life emissions of the CCU-based products, since they would not change in the CCU case with respect to the business-as-usual case if the product is the same. This set of rules is simple enough, in our view, to allow for a quite straightforward integration of CCU techniques into the current Swiss carbon pricing systems.

We can also draw from the results of our analysis a list of the main reasons to recommend Swiss policymakers to pursue the development of CCS and CCU in Switzerland:

- *a better integration with the global policy framework*: the international context appears to be more and more favorable to the integration of CCUS into the climate change mitigation toolkit. For example, as we have seen, the recent "Special Report on Global Warming of 1.5°C" of the IPCC (IPCC 2018) explicitly calls for negative emissions to be implemented on a large enough scale by 2050 in order for the international community to stay in the track of limiting global warming to 1.5°C. At different levels, the U. S., China or the EU have started to put into effect a number of policies aimed at promoting CCS and some CCU technologies. In these conditions, it is necessary for the Confederation to keep up with the increasingly fast pace of development of the net of global environmental policies which embed and support a number of federal policies. If Switzerland did not implement the same standards and regulations for CCUS which have been or will be developed in neighboring countries, or countries with which Switzerland enjoys close commercial relationships, this could potentially hinder the development of a large number of environmental, commercial and industrial projects in the medium- to long-term future;
- *expand the range of climate mitigation action*: as exposed in section 5.1.3, the federal policies currently in place to decrease GHG emissions do not appear to be sufficient to reach the current federal targets, let alone the more ambitious ones which, according to the IPCC, would be necessary to keep the increase of global temperatures below 1.5°C (IPCC 2018). Therefore, it is important to improve the federal climate policy not just strengthening the existing instruments, but also enlarging the range of such tools. CCUS appears to be one of

the most promising set of technologies and yet, as we have seen, is still almost completely missing from the Swiss environmental policy;

- *increase the industrial synergies*: in a perspective of circular economy, CCU processes would allow to "transform" CO_2 from waste to resource and thereby contribute to close the carbon loop by creating new symbiotic networks of interconnected manufacturing businesses, with a number of important benefits especially in the form of reduction of waste, carbon emissions and also fossil resources depletion.

It is worth noticing that, although in volume 2, part II we have chosen to draft the texts of a good number of our legislative provisions with reference to the existing (i. e. as of 2019) legal framework, i. e. the current version of the CO_2 Act, the CO_2 Ordinance etc., the actual content of these provisions could be also easily extrapolated to future updated versions of these legal acts.

We point out another relevant result of this work, consistent in a comprehensive breakdown of the CO_2 emissions in Switzerland, see volume 1, appendix C. While such data are of public access, they are usually reported in a way that mixes them together with the data relative to the other GHGs, in such a manner that it is very difficult to extract valuable information relative to CO_2 emissions alone. To the best of our knowledge, this is the first time that they have been selected and presented in a clear and organized way.

Finally, we conclude by stressing that, while most of the work related to this publication has been carried out in reference to the Swiss context, many of its results are not limited to this context and are in principle applicable to a vast range of situations outside Switzerland and even worldwide.

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A DEFINITIONS, ACRONYMS AND LEGAL TEXTS

A.1 TECHNICAL DEFINITIONS AND ACRONYMS

Atmospheric CO_2 residence time. The residence time of carbon dioxide in the atmosphere is the average length of time for which an individual molecule of CO_2 remains in the atmosphere before being taken up by the ocean or terrestrial biosphere (Köhler et al. 2018). The actual value of this residence time is still debated in the scientific community: however, according to the mainstream view backed by the IPCC reports the residence time of carbon dioxide in the atmosphere is currently estimated to be around 100-150 years (IPCC 2007).

Bioenergy with Carbon Capture and Storage (BECCS). BECCS is identical to CCS (see below), except that the CO_2 is released from biomass.

Carbon Capture and Storage (CCS). CCS consists in capturing, transporting, and finally injecting the CO_2 emitted by large emission sources (e.g. power plant, cement plant, incinerator) in suited geological formation.

Carbon Capture and Utilization (CCU). CCU considers CO_2 as a resource, which can be transformed to create marketable products (e.g. fuels, polymers), or directly used (e.g. fire extinguisher). By extension, the terms BECCU (Bioenergy with Carbon Capture and Utilization) and DACU (Direct Air Capture and Utilization) can also be used.

Carbon Capture, Utilization and Storage (CCUS). CCUS is a term designing both CCS and CCU processes.

Carbon footprint. The carbon footprint is an environmental indicator of the contribution to anthropogenic climate change of a process, product, activity or population. As such, it is difficult to be exactly calculated, especially because of our incomplete knowledge of necessary data and the complexity of interactions between the various contributing processes. For this reason, L. Wright, S. Kemp and I. Williams have proposed to define it as "a measure of the total amount of CO_2 and CH_4 emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as CO_2-eq using the relevant 100-year global warming potential (GWP100)" (Wright et al. 2011). In fact, CO_2 and CH_4 are the most important GHGs and the data regarding these emissions are usually available or can be easily gathered, whereas accurate data on the emissions of other GHGs are more difficult to find.

Carbon neutrality. Carbon neutrality, or having a net zero carbon footprint, refers to achieving net zero carbon dioxide emissions in two ways: by compensating carbon emissions with carbon removal (often through carbon offsetting), or simply by eliminating carbon emissions altogether.

Carbon offset. Carbon offset refers to a reduction in emissions of carbon dioxide or other greenhouse gases which is meant to compensate for emissions made elsewhere. Carbon offsets are usually measured in tonnes of carbon dioxide-equivalent (CO_2-eq). One tonne of carbon offset represents the reduction of one tonne of emissions of carbon dioxide or its equivalent in other greenhouse gases.

Direct Air Capture (DAC). DAC aims at extracting CO_2 from ambient air through physico-chemical methods.

DACCS. Direct Air Carbon Capture and Storage.

DACCU. Direct Air Carbon Capture and Utilization.

Eco-industrial park. An eco-industrial park is an industrial park designed to improve the social, economic and environmental performance of their resident firms, including through the promotion of industrial symbiosis and green technologies delivering resource efficiency and resulting in competitive advantage, promoting climate-resilient industries and green value chains, as well as inclusive and sustainable business practices and socially responsible relations with surrounding communities (UNIDO (United Nations Industrial Development Organization) 2019).

GHG(s). Greenhouse gas(es).

Negative Emissions Technologies (NETs). The term "negative emissions technologies" denotes a range of techniques for removing carbon dioxide from the atmosphere, thereby repaying the world's carbon debt—with interest. These technologies are also called Carbon Dioxide Removal (CDR) technologies. According to the IPCC, the world would need to rely significantly on these techniques to avoid increasing Earth's temperatures above 1.5 degrees Celsius, or 2.7 degrees Fahrenheit, compared to pre-industrial levels (IPCC 2018). The portfolio of NETs includes afforestation and reforestation, BECCS, DAC, soil carbon, biochar, enhanced weathering (Minx et al. 2018).

Reservoirs, sources and sinks. According to the IPCC guidelines (IPCC 2006), we consider that a reservoir is a "system which has the capacity to accumulate or release carbon". A reservoir becomes a source when more carbon is released than accumulated. Inversely, a reservoir is considered a sink when the amount of immobilized carbon increases.

A.2 UNITED STATES GOVERNMENT: AGENCIES AND DEPARTMENTS

US EPA. United States Environmental Protection Agency.

US DoE. United States Department of Energy.

A.3 SWISS GOVERNMENT: OFFICES AND DEPARTMENTS

DETEC. Federal Department of the Environment, Transport, Energy and Communication.

FOEN. Federal Office for the Environment. It is the Swiss federal government's centre of environmental expertise and is currently part of the DETEC.

SFOE. Swiss Federal Office of Energy. It is the country's competence centre for issues relating to energy supply and energy use at the DETEC.

A.4 LEGAL TEXTS: RELEVANT PROVISIONS

A.4.1 INTERNATIONAL LAW

United Nations Framework Convention on Climate Change (UNFCCC) of 9 May 1992.

Art. 2 - Objective

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

[...]

Art. 4 - Commitments

[1] All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall:

[...]

(d) Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems;

[2] The developed country Parties and other Parties included in Annex I commit themselves specifically as provided for in the following:

(a) Each of these Parties shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention, recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol would contribute to such modification, and taking into account the differences in these Parties' starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort regarding that objective [...].

Kyoto Protocol to the United Nations Framework Convention on Climate Change of 11 December 1997.

Art. 2

[1] Each Party included in Annex I, in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development, shall:

(a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as:

[...]

(iv) Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies;

[...]

A.4.2 EUROPEAN LAW

Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control ("Integrated pollution prevention and control (IPPC) Directive").

Art. 2 - Definitions

For the purposes of this Directive the following definitions shall apply: [...]

[2] 'pollution' means the direct or indirect introduction, as a result of human activity, of substances, vibrations, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment;

[...]

Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community ("2009 ETS Directive").

Art. 1 - Amendments to Directive 2003/87/EC

Directive 2003/87/EC is hereby amended as follows:

[...]

[11] Article 10 shall be replaced by the following:

Article 10

Auctioning of allowances

[...]

3. Member States shall determine the use of revenues generated from the auctioning of allowances. At least 50% of the revenues generated from the auctioning of allowances referred to in paragraph 2, including all revenues from the auctioning referred to in paragraph 2, points (b) and (c), or the equivalent in financial value of these revenues, should be used for one or more of the following: [...]

(e) the environmentally safe capture and geological storage of CO_2, in particular from solid fossil fuel power stations and a range of industrial sectors and subsectors, including in third countries;

[...]

[12] The following Articles shall be inserted:

Article 10a

Transitional Community-wide rules for harmonised free allocation

[...]

3. Subject to paragraphs 4 and 8, and notwithstanding Article 10c, no free allocation shall be given to electricity generators, to installations for the capture of CO_2, to pipelines for transport of CO_2 or to CO_2 storage sites.

[...]

8. Up to 300 million allowances in the new entrants' reserve shall be available until 31 December 2015 to help stimulate the construction and operation of up to 12 commercial demonstration projects that aim at the environmentally safe capture and geological storage (CCS) of CO_2 as well as demonstration projects of innovative renewable energy technologies, in the territory of the Union.

[...]

15 Article 12 shall be amended as follows:

[...]

(b) the following paragraph shall be inserted:

3a. An obligation to surrender allowances shall not arise in respect of emissions verified as captured and transported for permanent storage to a facility for which a permit is in force in accordance with Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide.

A.4.3 SWISS LAW

Federal Act on the Protection of the Environment (Environmental Protection Act, EPA) of 7 October 1983.

Art. 1 - Aim

[1] This Act is intended to protect people, animals and plants, their biological communities and habitats against harmful effects or nuisances and to preserve the natural foundations of life sustainably, in particular biological diversity and the fertility of the soil.

[2] Early preventive measures must be taken in order to limit effects which could become harmful or a nuisance.

Art. 2 - Polluter pays principle

Any person who causes measures to be taken under this Act must bear the costs.

[...]

Art. 7 - Definitions

[1] Effects are air pollution, noise, vibrations, radiation, water pollution or other interference in water, soil pollution, modifications of the genetic material of organisms or modifications of biological diversity caused by the construction and operation of installations, by the handling of substances, organisms or waste, or by the cultivation of the soil.

[2] Air pollution, noise, vibrations and radiation are referred to as emissions when discharged from installations, and as ambient pollution levels at their point of impact.

[3] Air pollution means modification of the natural condition of the air, in particular, through smoke, soot, dust, gases, aerosols, steams, odours or waste heat.

[...]

[6] Waste is any moveable material disposed of by its holder or the disposal of which is required in the public interest.

Art. 11 - Principles

[1] Air pollution, noise, vibrations and radiation are limited by measures taken at their source (limitation of emissions).

[2] Irrespective of the existing environmental pollution, as a precautionary measure emissions are limited as much as technology and operating conditions allow, provided that this is economically acceptable.

Art. 12 - Limitation of emissions

[1] Emissions are limited by issuing:

a. maximum emission values;

b. regulations on construction and equipment;

c. traffic or operating regulations;

d. regulations on the heat insulation of buildings;

e. regulations on thermal and motor fuels.

Art. 13 - Ambient limit values

[1] The Federal Council stipulates by ordinance the ambient limit values for assessing harmful effects or nuisances.

Art. 14 - Ambient limit values for air pollution

The ambient limit values for air pollution must be set so that, in the light of current scientific knowledge and experience, ambient air pollution below these levels:

a. does not endanger people, animals or plants, their biological communities and habitats;

b. does not seriously affect the well-being of the population;

c. does not damage buildings;

d. does not harm soil fertility, vegetation or waters.

Federal Constitution of the Swiss Confederation of 18 April 1999.

Art. 2 - Aims

[...]

[4] The Swiss Confederation is committed to the long term preservation of natural resources [...]

Art. 73 - Sustainable development

The Confederation and the Cantons shall endeavour to achieve a balanced and sustainable relationship between nature and its capacity to renew itself and the demands placed on it by the population.

Art. 74 - Protection of the environment

[1] The Confederation shall legislate on the protection of the population and its natural environment against damage or nuisance.

[2] It shall ensure that such damage or nuisance is avoided. The costs of avoiding or eliminating such damage or nuisance are borne by those responsible for causing it.

[3] The Cantons are responsible for the implementation of the relevant federal regulations, except where the law reserves this duty for the Confederation.

Swiss Civil Code of 10 December 1907.

Art. 713

Chattel ownership relates to movable physical objects and to forces of nature that may be the subject of legal rights and which do not form part of any immovable property.

Federal Act on the Reduction of CO_2 Emissions (CO_2 Act) of 23 December 2011.

Art. 1 - Aim

[1] This Act is intended to reduce greenhouse gas emissions and in particular CO_2 emissions that are attributable to the use of fossil fuels (thermal and motor fuels) as energy sources with the aim of contributing to limiting the global rise in temperature to less than 2 degrees Celsius.

[2] The Federal Council designates the greenhouse gases.

Art. 3 - Reduction target

[1] Domestic greenhouse gas emissions must be reduced overall by 20 per cent as compared with 1990 levels, by 2020. The Federal Council may set sector-specific interim targets.

Art. 4 - Measures

[1] The reduction target should in the first instance be achieved through measures under this Act.

[2] Measures that reduce greenhouse gas emissions in accordance with other legislation should also contribute to achieving the reduction target. These measures in particular include those in the fields of environment and energy, agriculture, forestry and timber industry, road traffic and the taxation of mineral oil, as well as voluntary measures.

Chapter 4 - Emissions Trading and Compensation

Section 1 - Emissions Trading Scheme (ETS)

Art. 15 - Participation by application

[1] Companies from specific economic sectors that operate installations with high or moderate greenhouse gas emissions may apply to participate in the emissions trading scheme.

[2] Each year the companies must surrender to the Confederation emission allowances or emission reduction certificates equal to the emissions caused by these installations. The Federal Council determines the extent to which emission reduction certificates may be surrendered. In doing so, it considers comparable international regulations.

[...]

Art. 17 - Exemption from the CO_2 levy

Companies under Articles 15 and 16 (ETS companies) are refunded the CO_2 levy on thermal fuels.

Art. 19 - Allocation of emission allowances

[1] The emission allowances are allocated annually.

[2] They are allocated free of charge to the extent that they are required for the greenhouse gas efficient operation of ETS companies. The other emission allowances are auctioned off. [...]

Ordinance on Air Pollution Control (OAPC) of 16 December 1985.

Art. 6 - Capture and removal of emissions

[1] Emissions shall be captured as fully and as close to the source as possible and shall be removed in such a way as to prevent excessive ambient air pollution levels.

B CLASSIFICATION OF THE MAIN CCU TECHNOLOGIES

In this appendix, we reproduce a table that we already presented in volume 1, chapter 3 and that shows the main CCU technologies with potential for commercial viability which are discussed in the literature. In this table, CCU technologies are classified according to the pathways of the recycled carbon dioxide, as explained in the next paragraphs.

In the context of CCU, the captured CO_2 is submitted to a process of valorization which can take different forms. We can distinguish two main pathways for CCU: conversion uses of CO_2 and non-conversion uses of CO_2. Each of these pathways can then be further divided in two sectors, according to whether the storage of the CO_2 is permanent or non-permanent:

- <u>*Conversion - Non-permanent storage*</u>. The situation in which the CO_2 is subject to conversion processes. During these processes, the CO_2 endures chemical reactions which typically break its chemical bonds to form new ones and the carbon atoms are recycled into new, useful products. For example, in a CCU process known as "algae cultivation" CO_2 is absorbed by microalgae which can then be converted into proteins, fertilizers and biomass for biofuels.
- <u>*Non-conversion - Permanent storage*</u>. The situation in which the CO_2 is not chemically converted and therefore the carbon atom remains bounded into the CO_2 compound after the process. For instance, in Enhanced Oil Recovery (EOR) processes, the captured carbon dioxide is injected in a liquid-like state into an existing oil well reducing the viscosity of the oil, therefore increasing the amount of oil that can be produced from the well. Most of the CO_2 injected into the well becomes trapped in the rock and is permanently stored in the pore spaces, whereas the portion of the injected CO_2 which is recovered with the oil is immediately separated and combined with CO_2 arriving from the original source for re-injection into the formation.

Ultimately, all the CO_2 injected in the well will be permanently stored in the formation.

- *Conversion - Permanent storage*. In mineralization processes, e.g. carbon mineralization, carbon dioxide chemically reacts with other compounds, generally calcium- or magnesium-containing minerals, to produce new compounds which can be used e.g. as a construction material. In this case, the carbon atom is permanently stored in this new material.
- *Non-conversion - Non-permanent storage*. This is the case of desalination processes, which do not appear in the list of Table B.1. In desalination processes, CO_2, mixed with H_2O brine at high pressure and low temperature, forms a hydrate of CO_2 surrounded by H_2O molecules. The hydrate is removed and rinsed, and then goes through multiple stages to remove dissolved solids in the brine, resulting in an exhaust stream of potable water (Nemitallah et al. 2019). The brine is then disposed.

A further discussion of this table can be found in volume 1, chapter 3.

Classification of the main CCU technologies		*Technology*	*Description*	*Residence time of CO_2*	*Categorization*
Conversion	*Mineralization*	Carbon mineralization	Mildly concentrated CO_2 (e.g. power station flue gas) is contacted with mineral-loaded alkaline brine (in mineral or industrial waste products). The CO_2 present in the gas precipitates out as mineral carbonates (limestone / dolomite equivalent precipitates). The resulting product can be further processed to form an aggregate equivalent product for the construction industry, which can potentially substitute a portion of Portland Cement in concrete and therefore decrease the carbon emissions in the sector of cement production.	Permanent	Substitution (cat. 2), storage (cat. 4)
		Concrete curing	Waste CO_2 flue gas stream is used to cure precast concrete, limiting the need for heat and steam in the curing process. CO_2 is therefore stored as an unreactive limestone within the concrete. The use of CO_2 could result in an accelerated curing process. Moreover, there is a net effect of substitution of CO_2-emitting processes (e.g. for heat production).	Permanent	Substitution (cat. 2), storage (cat. 4)
		Bauxite residue carbonation	The extraction of alumina from bauxite ore results in a highly alkaline bauxite residue slurry known as 'red mud'. Concentrated CO_2 can be injected into the red mud slurry to partially neutralise the product, improving its manageability, reducing its disposal costs and limiting its potential environmental impacts. In the neutralisation process, the CO_2 is converted to mineral form (typically carbonates), which can be used as construction materials (cement, bricks, tiles, aggregate	Permanent	Storage (cat. 4)

Classification of the main CCU technologies		*Technology*	*Description*	*Residence time of CO_2*	*Categorization*
Conversion	*Mineralization*		blocks and wood substitute). Also, this technology reduces the cost of red mud disposal.		
	Biological	Algae cultivation	Microalgae absorb CO_2 and then can be converted for example into proteins, fertilizers and biomass for biofuels, thereby replacing fossil resources. Some possible utilization avenues can also lead to semi-permanent storage of CO_2. However, the high surface requirement for cultivation may reduce the commercial viability of this technology in areas where land prices are high.	Non-permanent	Substitution (cat. 2)
		Greenhouse enrichment	Various systems have been proposed to increase food productivity while sequestrating CO_2 from ambient air by enriching the air in a greenhouse with captured CO_2, cf. Bao et al. 2018.	Non-permanent	Substitution (cat. 2)
		Succinic acid biosynthesis	Captured CO_2 can be used for succinic acid production in a few biochemical processes (cf. Cheng et al. 2012), whereas today succinic acid is mainly produced from fossil resources (through maleic acid hydrogenation).	Non-permanent	Substitution (cat. 2)
	Chemical	Power-to-fuel (or power-to-X)	CO_2 is electro-chemically converted into gaseous or liquid energy carriers or industrial feedstocks.	Non-permanent	Substitution (cat. 2)
		Formic acid synthesis	CO_2 is electro-chemically converted in water to produce formic acid, replacing the use of fossil fuel as raw material (cf. Pérez-Fortes et al. 2016).	Non-permanent	Substitution (cat. 2)

Classification of the main CCU technologies		*Technology*	*Description*	*Residence time of CO_2*	*Categori-zation*
Conver-sion	*Chemical*	Polymers/ chemical feedstock	CO_2 is transformed into polycarbonates and other chemicals.	Non-permanent	Substitution (cat. 2)
		Urea yield boosting	Ammonia and CO_2 are converted to urea fertilizer, thereby replacing fossil fuels that are typically used in urea production plants.	Non-permanent	Substitution (cat. 2)
Non conversion		Enhanced oil/gas recovery	CO_2 is injected into an existing oil or gas well to increase pressure and reduce the viscosity of the substance, increasing the amount of the substance that can be recovered. This technology is considered a commercially mature technology, having first been deployed in the 1970's.	Permanent	Storage (cat. 4)
		Enhanced geothermal systems	Supercritical CO_2 transfers geothermal heat or generates power directly through a supercritical CO_2 turbine. This would achieve geologic storage of CO_2 as an ancillary benefit. However, this technology is still in a pre-commercial phase.	Permanent	Substitution (cat. 2), storage (cat. 4)
		Enhanced coal bed methane	CO_2 is injected into partially depleted coal seams, where it's absorbed by coal, in turn displacing methane to the surface for it to be captured and consumed as fuel.	Permanent	Storage (cat. 4)

Table B.1: List of the main CCU technologies classified according to the pathways of the recycled carbon dioxide.
Source: derived from Global CCS Institute 2011.

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Carbon capture, utilization and storage (CCUS) technologies have been proposed in recent times to mitigate anthropogenic climate change. Although already present in other Western countries, public policies regulating the deployment of CCUS facilities are still lacking in Switzerland.

In this second volume, we analyze the current legal and institutional framework that revolves around the complex public policy issues related to CCUS. We then present a series of detailed proposals to develop a coherent, integrated and sustainable public policy of CCUS in the Swiss context.

Les technologies de capture, d'utilisation et de stockage du carbone (CUSC) ont été proposées ces derniers temps pour atténuer le changement climatique d'origine anthropique. Bien que déjà présentes dans d'autres pays occidentaux, les politiques publiques encadrant le déploiement des installations de type CUSC font encore défaut en Suisse.

Dans ce deuxième volume, nous analysons le cadre juridique et institutionnel actuel autour des enjeux complexes de politique publique qui sont impactés par le développement du CUSC. Nous présentons ensuite une série de propositions détaillées en vue de créer une politique publique cohérente, intégrée et durable du CUSC dans le contexte suisse.