Policy instruments for bioenergy development

A qualitative study of current and prospective policy instruments facilitating bioenergy development in the transition to a fossil free future

Master's thesis in Sustainable Energy Systems

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

To mitigate climate change the EU has set a goal of climate neutrality by 2050. An important Swedish milestone is the transition of the heating sector by 2030 where bioenergy plays a significant role. This thesis performs a qualitative study of current and future policy instruments in Sweden and the EU facilitating bioenergy development in the transition to a fossil free future. Semi-structured interviews were conducted with 25 persons from relevant areas, including energy actors, bioenergy providers, academics and environmental actors. The data obtained was analysed using grounded theory and the results were further analysed based on insights from a literature review. A key finding was that there is currently a great uncertainty concerning the future of policy instruments implying there is no clear answer to what is best to invest in. However, the interviewees expressed policy instruments need to be bold and long term to reduce investment risks in new technology. They also stated that the market should continue to drive the transition, meaning everything has to be profitable in and by itself. Concerning bioenergy feedstock options for the energy sector in Sweden, the interviewees agreed it should mainly consist of residues. Five categories were identified as interesting for further investigation: industrial byproducts from forestry and construction, forest residuals, domestic and industrial waste, agricultural residues as well as various organic waste flows suitable for biogas production. Moreover, the implementation of RED II is considered the most important environmental policy instruments to keep monitoring for further bioenergy development.

Keywords: Sweden, bioenergy, feedstock, environmental policy instruments, interview study

Executive Summary

According to the Intergovernmental Panel on Climate Change, the world needs to become climate neutral within this century to mitigate climate change why the EU aims to have net zero emissions by 2050 and Sweden already by 2045. An important Swedish milestone is the transition to a climate neutral heating sector in Sweden by 2030 where bioenergy plays a significant role. The energy company Göteborg Energi aims to become fossil free by 2025 and has an interest in different available bioenergy feedstock options as well as policies and regulations that influence their attractiveness. Also bioenergy development and the regulatory context in the EU is of high interest.

Given this background, this thesis aims to improve knowledge of how bioenergy development may be affected by current and prospective environmental policy instruments in Sweden and the EU. A second aim is to identify the bioenergy feedstock options that are most interesting for further investigation. The study is limited to only look at policy instruments in Sweden and the EU. A distinction is made between biomass used for heat and electricity (bioenergy) and for transport (biofuels), where focus lays on the former. However, some of the included policy instruments also address biofuels. No deep-dive into details is performed, instead, a holistic, comprehensive perspective is adopted to consider the complexity of the roles policy instruments and bioenergy play in the transition to a fossil free future. Three research questions are established:

1. What is the current situation, and tendencies for future development, concerning bioenergy related policy instruments in Sweden and the EU?
2. What challenges and possibilities are there in the fossil free transition?
3. Which bioenergy feedstock options are the most interesting for further investigation?

To achieve the aim and answer the research questions, a qualitative study was performed based on 25 semi-structured interviews. The interviewees were found using both purposive and snowball sampling and they were divided into four categories based on their role: energy actors, bioenergy providers, academics and environmental actors. The common denominator is their extensive knowledge in the field, and the interviewees together cover a broad range of aspects connected to the topics studied. The data was analysed using grounded theory with the key process of open coding to break down the interview results into concepts that were categorised, thus identifying common and diverging opinions from the interviewees.

The presentation of results is divided into three parts. The first and most extensive part concerns the interview findings, which are divided into five categories: policy instruments, fossil free transition, energy systems, bioenergy and carbon capture and storage (CCS). The second part constitutes of a policy landscape overviewing current and prospective Swedish and European policy instruments. The table below presents a compilation of the included policy instruments, divided into four categories as proposed by Sterner and Coria (2012).

Policy instruments in the form of regulations	Policy instruments using markets	Policy instruments creating markets
EU Climate law	Swedish/EU carbon tax	EU Emissions trading system
Swedish Environmental Code	Swedish energy tax	
EU 2030 Climate & energy framework	Swedish waste incineration tax	
EU Effort Sharing Regulation	Swedish NO_x charge	
EU LULUCF Regulation	Swedish Electricity certificate system	**Policy instruments engaging the public**
EU Renewable Energy Directive	Swedish CCS support	Roadmap for the heating sector
Swedish Reduction obligation	Swedish Klimatklivet	
Swedish Forestry Act	EU Innovation fund	
EU Common Agricultural Policy		

The third part treats bioenergy feedstock options and their respective potentials and prospects, thus addressing the third research question. Five categories are identified as interesting for further investigation where the common denominator is an underlying rationale to make use of residues and aim towards a more circular bioeconomy: industrial byproducts from forestry and construction, forest residuals, domestic and industrial waste, agricultural residues as well as various organic waste flows suitable for biogas production. Finally, the results of this study boil down to a number of key insights:

- There is great uncertainty concerning the future of policy instruments, which implies that there is no clear answer to what is best to invest in.
- The largest uncertainty is political uncertainty, which creates unstable market conditions meaning there are high risks for investors.
- Clarity, distinctions and long-term perspectives in policy instruments are identified as necessary to handle the uncertainty and the investment risks.
- Companies need to collaborate and find sustainable and profitable solutions even in the lack of political support.
- Policy instruments, bioenergy options and technical solutions need to have a holistic approach and be optimised based on local conditions.
- In Sweden, residues and waste are considered most interesting for bioenergy applications.
- The implementation of RED II in 2021 will likely affect what is considered sustainable biomass and it is therefore important to engage in the development related to RED II.

To conclude, there are a lot of measures already in place to facilitate the fossil free transition, and bioenergy will continue to play an important role. It is possible to expand the use of bioenergy, especially through increased use of residuals from forestry and agriculture, as long as this is done sustainably. Concerning future support and regulations, these are issues that come with uncertainty and need to be continuously monitored.

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We would like to extend our heartfelt appreciation to all the people who participated in the interviews and contributed with their extensive knowledge without whom this thesis would not have been near as interesting as it is today. We are also very thankful of Dan Paulin for educating us on qualitative analysis and providing us with the tools to carry out the interview part of this work.

Finally, we send our thanks to friends and family for proofreading, discussing and supporting us during the project.

Thank you!

Elin Winberg and Lisa Winberg, Gothenburg, August 2020

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Abbreviations

BECCS	Bioenergy with carbon capture and storage
CAP	Common Agricultural Policy
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CHP	Combined heat and power
DAC	Direct air capture
DH	District heating
dLUC	Direct land use change
EED	Energy Efficiency Directive
EU ETS	EU Emissions Trading System
GHG	Greenhouse gas
HFCs	Hydrofluorocarbons
iLUC	Indirect land use change
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LUC	Land use change
LULUCF	Land use, land use change and forestry
NECP	National energy and climate plan
PFCs	Perfluorocarbons
PV	Photo-voltaic
RED I	Renewable Energy Directive from 2009
RED II	Recast Renewable Energy Directive from 2018
REP	Refunded emissions payment
RSB	Roundtable on Sustainable Biomaterials
SDGs	Sustainable development goals
SOU	Statens offentliga utredningar (Governments Official Investigations)
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

This master thesis on policy instruments for bioenergy development performs a qualitative study of current and prospective policy instruments facilitating bioenergy development in the transition to a fossil free future. The thesis is done in cooperation with the division of Physical Resource Theory at the department of Space, Earth and Environment at Chalmers University of Technology and the energy company Göteborg Energi AB. In this first section, the background, aim and research questions are presented, where-after Section 2 offers underlying theory on bioenergy, sustainability and environmental policy instruments. In Section 3 the chosen method for the 25 qualitative interviews, data collection and analysis are described. The results are divided into three main parts in Section 4; an assembly of the interview findings, a compiled policy landscape for Swedish and European Union (EU) policies, and a collection of prospective bioenergy feedstock options. Lastly, Sections 5 and 6 presents discussion and conclusions respectively.

1.1 Background

In 2015, the nations of the world gathered around the goal of combating climate change in the famous Paris Agreement. By signing the agreement, each nation promises to contribute to keep global warming from exceeding 2°C above to pre-industrial levels [1]. Following this, the Intergovernmental Panel on Climate Change (IPCC) provided a special report in 2018 stating the world needs to become carbon neutral within this century [2]. To avoid surpassing this limit and increase the efforts in combating climate change, the EU presented the European Green Deal in December 2019, a vision of having net zero greenhouse gas (GHG) emissions in all of the EU by 2050 [3]. The European climate law from 2020 legally binds the union members to reach climate neutrality by 2050, along with a pathway on how to achieve this target [4]. One Green Deal policy area concerns clean energy and states that to achieve net zero emissions, the energy system needs to be decarbonised since 75% of the GHG emissions today in the EU comes from the production and use of energy [5]. As Sweden strives towards being a leading country, achieving the goal of zero emissions is set to five years earlier than required by the EU, in 2045 [6]. Sweden has striven towards this since the sprouting of the Paris Agreement, why the Government decided on the initiative Fossil Free Sweden in 2015, which is a platform for actors who want to contribute in the transition. The different sectors are encouraged to set up roadmaps on how to become fossil free while keeping their competitiveness [7]. One of these sectors is the heating sector where around 50 actors on the heating market, including Göteborg Energi, together have created a roadmap with the goals of fossil free heating by 2030 and climate positivity by 2045 [8].

Göteborg Energi provides the citizens of Gothenburg with power and heat. The district heating (DH) in 2019 came from 70% recycled energy, 19% renewable energy and 11% fossil energy. The fossil part is natural gas and oil used in two combined heat and power (CHP) plants used to meet peaks in heat demand. The renewable energy share comes from bioenergy production, wind farms and solar photo-voltaic (PV) installations. The bioenergy used today is mainly logging residues, meaning branches, roots, tops and other woody debris. As for the share of recycled energy in the Gothenburg DH system, it is partly waste heat from nearby refineries and partly from the local waste incineration plant [9]. As a part of their contribution to a more sustainable city, Göteborg Energi has increased their ambition of achieving a fossil free DH production. Instead of reaching it by 2030, following the goal of the roadmap for the heating sector, they now aim at having it done by 2025 [10]. Thus, Göteborg Energi is preparing for a transition from fossil fuels and is interested in knowing the different available bioenergy feedstock options, the regulations that come along with them, how bioenergy is currently used in Europe and how policy instruments are used to quicken the transition.

1.2 Aim and scope

This thesis aims to improve knowledge of how bioenergy development may be affected by current and prospective environmental policy instruments in Sweden and Europe. A second aim is to identify bioenergy feedstock options interesting for further investigation.

To achieve this, a qualitative study is performed alongside a literature review. The study targets actors related to the energy sector and the investigation is limited to include only bioenergy related policy instruments from Sweden and the EU, since these impact the Swedish scene the most. A distinction is made between biomass fuels for energy (bioenergy) and transport (biofuels), where the transport sector is excluded from the scope and focus lays on the energy sector. However, some policy instruments treat both simultaneously whereas biofuels will inevitably be somewhat discussed. No deep-dive into details is performed, instead a holistic, comprehensive perspective is adopted to consider the complexity of the roles policy instruments and bioenergy play in the transition to a fossil free future.

1.3 Research questions

With the above mentioned aim, the research questions of this thesis are as follows:

1. What is the current situation of bioenergy related policy instruments in Sweden and Europe and what are the tendencies for future development?
2. What challenges and possibilities are there in the fossil free transition?
3. Which bioenergy feedstock options are the most interesting for further investigation?

2 Theory

Underlying theoretical content important for this thesis is presented hereafter. First, bioenergy and its importance are defined followed by introductions of biomass production, advantages and disadvantages with bioenergy and carbon capture and storage. Thereafter, aspects of sustainability including sustainability criteria, biodiversity and land use and land use change are highlighted. Further, the fundamentals of environmental policy instruments along with current Swedish and EU ones are presented. Lastly, future aspects of bioenergy and environmental policy instruments are raised.

2.1 Bioenergy

Bioenergy is the energy released during conversion of biomass, and it is a renewable source of energy for heat and electricity production as well as for transportation fuels [11]. A distinction is done between bioenergy and biofuels, where bioenergy implies biomass used for energy production whereas biofuels refer to refined liquid and gaseous biomass mostly used for transport. Note that some liquid fuels can be used for bioenergy purposes as well, such as bio-oils for heating. This thesis focuses on bioenergy, thus targeting mainly gaseous and solid bioenergy.

In Sweden today, bioenergy stands for 38% of the nation's energy use [12]. Bioenergy along with electricity is stated as the answer to the challenge in becoming fossil free, according to the roadmaps included in the initiative for a fossil free Sweden [7]. Svebio, a commercial environmental organisation promoting bioenergy, presented in 2020 a roadmap on how bioenergy can be used to meet the future demands coupled with the fossil free transitioning. There is a strong belief that bioenergy is capable of fulfilling these demands, mainly by using a larger part of the logging residues, growing energy crops and making use of agricultural residues [12].

2.1.1 Biomass production

Biomass can refer to several things and sprouts from many different sources. In an ecosystem, biomass is defined as solar energy and CO_2 stored in organic matter through photosynthesis, and the organic matter can then be accumulated in plants, trees, algae and the like. The organic matter could also be decomposed or consumed by herbivores or fire. While growing, the biomass absorbs carbon from the air and the accumulated biomass can then be used for energy purposes. The action of lowering the net carbon concentration in the atmosphere is referred to as a carbon sink [13].

Another definition of biomass, from the recast Renewable energy directive from 2018 (RED II) [14], is "the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin". This portrays the broad spectra of biomass and indicates its versatility. In this thesis, the main focus will be on biomass from forestry, waste and agriculture. While waste in its entirety is not defined as bioenergy, waste incineration is seen as recycling in the form of energy recovery why it is still considered sustainable [15]. However, since waste is used in a similar way to biomass in the case of district heating (DH) and energy production, this thesis will categorise waste with other bioenergy feedstock options.

Forestry

Forests are of great importance to society. They bind CO_2, can promote rich biodiversity and provide opportunities for tourism and recreation. The forestry sector is a big industry in Sweden, providing work and income in both forest management and forest industry [16]. Swedish forests account for 70% of the land area and about half of the forest is owned by private individuals. A fourth is owned by forest companies and the main part of the remaining fourth is state-owned. This makes Sweden one of the countries with the largest share of private-owned forests [17]. Locally in the county of Västra Götaland, the share of private forest owners is higher than the national average at almost 80% [18]. Oftentimes, the private forests have been inherited for several generations making the owners adopt a long-term perspective in their forest management to help their forest prosper for many generations to come [17]. Since the 1920s, the net timber stock in Sweden has increased due to forest growth being larger than what is taken out through logging [19].

There are both primary and secondary bioenergy sources from the forest. Primary forest biomass is logging residues from felling and thinning, stumps and rotten or sprinted trunks that are unsuitable for industry. The residues are mostly tops and branches which are dried and converted into wood chips [20]. This will further be referred to as forest residuals. Secondary forest biomass is byproducts from pulp- and sawmills, such as bark, wood chips and sawdust. There is also tertiary forest biomass consisting of what is left after use and recycling of wood products, such as paper products in municipal waste, waste and demolition wood that are burnt in combined heat and power (CHP) waste plants, or sewage sludge that can be used for biogas production. These primary, secondary and tertiary biomass fuels are recovered along the supply chain of wood products that are always seen as more valuable. Biomass for energy is the last step in the wood use cascade [20]. A flowchart over the biomass and energy flows from Swedish forests made by Svebio and the International Renewable Energy Agency (IRENA) is presented in Figure 1 [20].

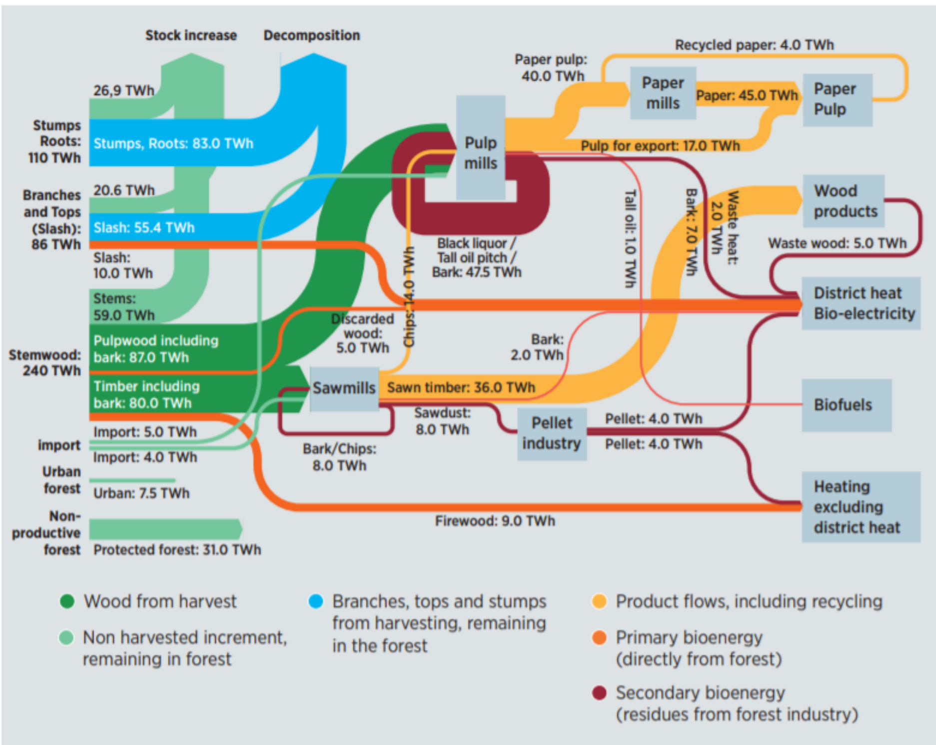

Figure 1: *Biomass and energy flows from the Swedish forest [20].*

From this figure, it can be seen that most of the logging residues are left to decompose in the forest, eventually releasing CO_2. Using logging residues for energy purposes is therefore seen as a time shift of the CO_2 release. Today, less than 10% of the tops and branches and none of the stumps are used for energy purposes [12]. According to Svebio and IRENA, it would be possible to increase the use of tops, branches and stumps in the future as long as a sufficient amount, half of the slash and 20% of the stumps, is left in the forests as support for the biodiversity, soil protection and nutrient balance [20]. However, not everyone agree more tops, branches and stumps can be taken out from the forest. For example, a report on boreal forests from 2011 by the the Swedish Society for Nature Conservation (Naturskyddsföreningen) and WWF [21] states outtake of stumps would require up to 30 years to reach positive climate effects, why they argue all stumps should be left in the forests.

Sweden has a national forest program with a strategy stating that Sweden should be a model for sustainable forest management in the bioenergy transition [16] and was early in adopting a forestry policy, known as the Forestry Act, treated in Section 2.4.2. Sweden has adopted the definition on sustainable forest management as defined by Forest Europe, a pan-European forest collaboration in 1993 [22]; “the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems”. There is an important balance between production and environmental aspects, why the program creates a platform for intersectional collaboration and provides a long term orientation and stability for Swedish forestry [16].

Waste

Biomass from waste includes both incineration to generate heat and electricity and anaerobic digestion to produce biogas. In the first case, municipal waste is incinerated in CHP plants that produce both heat and electricity. CHP plants have a heat to power ratio which is normally predetermined by the design of the plant and cannot be largely influenced during operation [23]. In recent years, a lot of research has been carried out into finding more flexible operation of the ratio of heat and power as a means to manage variations in the electricity systems due to variable renewable energy sources [24]. The heat produced in waste incineration is distributed to consumers via a DH system, which is a closed loop with heat exchangers where the cooled water is returned to the central station to be heated again. Apart from being provided through waste incineration, DH can be provided through heating plants or waste heat from adjacent industries [25]. In Sweden, waste incineration is widely used, given the large heat demand, especially in wintertime. This has the effect of both generating heat and preventing waste from ending up in landfills [26]. Only the waste that cannot be utilised in any other way ends up in landfills, which accounts for less than 1% of the Swedish domestic waste, making Sweden the leading European country concerning waste incineration [15, 27]. Other European countries even export waste to Sweden at a charge, so that Sweden takes care of incineration and prevents landfill [26]. In addition, incinerating municipal waste for heat can be considered as recycling in the form of energy recovery, according to both Swedish and EU regulations [15]. Apart from the municipal and domestic waste, also construction waste in the form of demolition wood can be used for incineration. This wood can be turned to recycled wood chips that can be used directly in CHP plants or for other heating purposes and not only in waste incineration[28]. In fact, chips of recycled wood is fiscally considered bioenergy [29].

Turning to the second case, waste of biological origin, such as organic waste and sludge, can be turned into biogas by anaerobic digestion, where microorganisms decompose the waste. This is the main way of producing biogas in Sweden today. Another way of producing biogas is through gasification, which is done mainly from forestry or agricultural residues [30]. The biogas produced, with either method, consists mainly of methane and CO_2 and can be used both as biofuel or bioenergy. For biofuel use, further refining is needed where, amongst other processes, the CO_2 is removed. Biogas as bioenergy can be used both in industrial applications for heating or substituting fossil gas as raw material, and in the energy sector in CHP plants to produce heat and electricity to the municipality [31]. There are several advantages of using biogas for energy purposes instead of solid biomass, where one is that fuel-gas technologies such as gas engines or gas turbines can be used which have higher efficiencies than regular steam cycles. The gasification process permits the removal of contaminants, reducing the amount of contaminants in post-combustion flue gases. Further, the biogas itself has improved combustion properties compared to solid biomass, having a higher heating value and burning more easily [32, 33].

In 2008, the EU issued a directive on waste where a waste hierarchy was introduced that first and foremost promotes the prevention of waste generation. Where this is not possible, re-use is preferred over recycling. Thereafter recycling implies first recycling of materials and then other recovery, such as energy recovery by waste incineration. All these steps are necessary to minimize the amount of waste that reaches the ultimate step, disposal on landfill [34]. This waste hierarchy is illustrated in *Figure 2*.

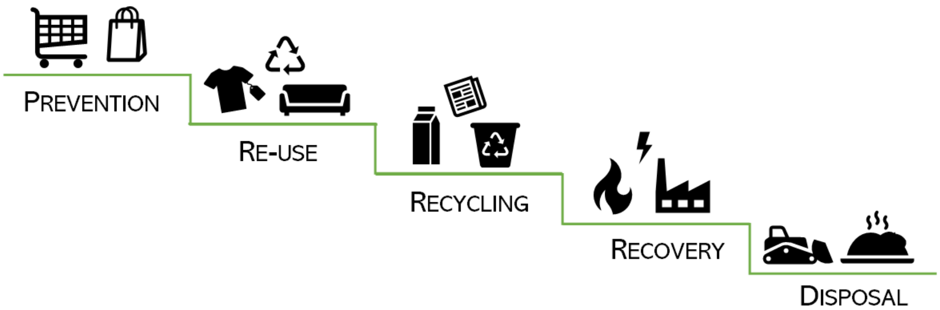

Figure 2: *Illustration of the waste hierarchy's five steps. First, waste generation should be prevented. Where this is not possible, re-use is encouraged after which comes materials recycling. Thereafter comes energy recovery and lastly disposal on landfill.*

Agriculture

For the agricultural sector, biomass production for bioenergy includes a vast variety of biomass descending from either dedicated energy crops or agricultural residues. Dedicated energy crops are specifically grown for bioenergy use, even though many of them are edible. Oilseeds, such as rapeseed or soybean, as well as many crops, i.e. wheat, corn and sugarcane, are intended for biofuel production, but could also be used in energy production as a replacement for oil. Woody or grassy energy crops such as coppice, poplar and willow are on the other hand directly aimed for the energy sector to generate heating, cooling or electricity [35].

Agricultural residues include both primary and secondary residues. Primary residues occur at farm level, such as harvest or pruning residues and manure. Secondary residues originate from the processing and refining, such as husks, shells and fruit pomace. Agricultural residues constitute a good bioenergy feedstock for heating purposes. However, there is a lot of untapped potential today, since there are neither incentives nor sufficient logistics for properly collecting the residues [35].

2.1.2 Carbon capture and storage

One major advantage of bioenergy is the prospect of net negative emissions of CO_2, also known as climate positivity. When industrial processes use biomass as an energy carrier, the produced CO_2 can be captured. This is commonly referred to as bioenergy with carbon capture and storage (BECCS). According to Svebio, bioenergy is the only source that could generate negative emissions with the technology available today at a reasonable cost [12].

Carbon capture and storage (CCS) is an upcoming technique, where CO_2 is separated and captured from the flue gases of an industrial production plant and thereafter transported to final storage, where the CO_2 is sequestered, either in bedrock or ocean sediments [36]. According to the IPCC, CCS is an important tool in reaching the climate goals, and it appears in most modeled pathways achieving the 1,5°C goal, since fossil fuel use is predicted to continue in the coming years [2]. However, CO_2 capture is not yet economically feasible in a commercial scale for the energy sector. Different technologies for capture are still under development, but demonstration plants are now popping up more frequently [37, 38]. It is thus reasonable to assume CCS techniques will expand even more in the years to come, considering also the large investments in CCS research. In fact, in January 2020 the Governments Official Investigations (Statens offentliga utredningar, SOU) made an investigation on the pathway towards a carbon-positive future, where they suggest reversed auctions as a means to incentivise BECCS and acquire negative emissions. They further state these plants need to be taken into operation during the 2020s to ensure reaching the 2045 goal of net zero emissions [39].

Another way of capturing CO_2 is through direct air capture (DAC), where CO_2, as the name suggests, is caught directly from the atmosphere. It is an emerging technology where the main obstacle today is the cost [40]. However, the entrepreneurial company Climeworks launched the world's first commercial-scale DAC plant in 2017 [41]. In addition, a study from 2019 suggests DAC can play a crucial role even in a system where point source CCS and defossilisation is implemented to a large extent since DAC offers purely negative emissions by reducing the atmospheric concentrations without causing any additional emissions [40].

Once the CO_2 has been captured, it can either be stored or utilised as raw material. For the first case, caught CO_2 is sequestered into in bedrock or ocean sediments as mentioned above. This has been done since 1996 at the Sleipner platform, a Norwegian sub-seabed formation that was originally a petroleum field in the North Sea [42]. This storage site would likely be of interest also for CO_2 caught in Sweden. However, transporting captured CO_2 across the Swedish border has up until recently not been legal, but this was changed in June 2020 when the Government fulfilled their commitment of removing the legal barriers of implementing CCS presented 2019 in their action plan for climate policy [43]. The decision taken in June renders exporting CO_2 with the aim of under-water storage legal [44], meaning the Norwegian storage site is now a real possibility. Another storage possibility could be the southeastern part of the Baltic Sea offshore to Gotland, or offshore southern Skåne, since these locations have the right geological foundations [45]. For the second case, the caught CO_2 can be transformed into useful products, such as materials, fuels and chemicals instead of being stored underground. This is known as carbon capture and utilisation (CCU) and can be used both at point sources such as industries and via DAC. It thus reduces the carbon footprint at the same time as it lowers the demand for fossil raw material. CCU, as well as CCS, is dependent on policy support that promotes investments to make it commercially feasible [46].

2.2 Sustainability

Sustainability is a broad concept that can have different meanings in different disciplines, some of which can even be conflicting [47]. Both the European Commission and the United Nations (UN) defines sustainable development as the "development that meets the needs of current generations without compromising the ability of future generations to meet theirs" [48, 49]. Normally when talking about sustainable development, it includes three established pillars, environmental, economic and social, which all need to be considered with regard to each other [47]. The UN specifies this as "harmonizing economic growth, social inclusion and environmental protection" [49]. Note that there is no universal definition for these three pillar as they have emerged over time in various sources [50].

Environmental sustainability includes aspects of biodiversity, functioning ecosystems, water and air quality and is described to be achieved when biological systems' capacity of maintaining their functions and processes is sustained over time. One important issue is that nature provides both resources that can be traded on a market and indirect contributions from ecosystem services, such as water purification. It can thus be difficult to quantify natural capital and assign the correct value to nature itself [47]. The economic dimension of sustainable development can in short be described as maintaining society's well-being over time. This includes aspects of using resources cost-efficiently, economic growth and economic development while simultaneously preserving the total capital, be it natural, industrial or social [47]. Social sustainability is the most ambiguous of the three dimensions, and as such is often not given the same ponderosity as the other two. This is partly due to social sustainability being based on socio-cultural values and politics rather than scientific facts, and partly to the lack of a conventional definition [51]. The UN highlights eradicating poverty as one of the most important aspects of all sustainable development [49]. Other important social aspects are equity, health, education and demography as well as welfare and quality of life [51, 52].

Recall that there is no universal agreement on how to interpret the dimensions and their competition with each other. What is deemed sustainable and what is included in each dimension lies in the eye of the beholder, their values and perception of society, meaning there are many ways of interpreting and developing the concepts. Consequently, sustainability is a difficult concept to define and this section only aims at giving an introduction to the concept.

2.2.1 Sustainability criteria

Regarding bioenergy feedstock options and policy instruments influencing them, environmental and economical aspects of sustainable development are the most prominent whereas social aspects figure in the background. One of the most important policies regarding bioenergy in Europe is the Renewable Energy Directive from 2009, amended by RED II in 2018. In the first directive, the European Commission included sustainability criteria for bioliquids, solid and gaseous biomass fuels to ensure bioenergy production being done sustainably. These criteria were reinforced in RED II to apply for all biomass, no matter where it was produced or where it is used as well as to include indirect land use changes [14]. In short, bioenergy fuels are not allowed to be made of raw material obtained from highly biodiverse areas or lands with high-carbon stock, such as wetlands and certain forests. Peatland is also forbidden unless there is evidence of sustainable harvesting. Bioenergy from forest biomass requires enough national regulations regarding forest management systems to ensure sustainable harvesting operations and to maintain and enhance the carbon stocks and sink levels. The last criteria is there to avoid land use change (LUC) effects [14]. However, most of the RED II criteria apply specifically to liquid biofuels but there are also other ordinances regulating bioenergy production and land use, such as the regulation on land use, land use change and forestry (LULUCF) and the European Green Deal, which are treated in Section 2.4.3.

Moreover, in 2015 the UN presented 17 sustainable development goals (SDGs) along with an agenda for sustainable development to guide the member states onwards in tackling the challenges of transforming our world into a better place for everyone [53, 54]. The SDGs cover several aspects of all three dimensions of sustainability [53]. In addition, Sweden has 16 own environmental goals similar to the SDGs [55], 15 of which established already in 1999 while the 16th, biodiversity, was added in 2005 [56], along with a generation goal of "leaving a society to the next generation where the major environmental issues are solved, without causing increased environmental and health problems outside Sweden's borders" [57].

2.2.2 Biodiversity

An essential aspect to consider with biomass production is the preservation of biodiversity. Biodiversity can be described by three main parts; diversity of ecosystems, diversity between species in an ecosystem and diversity within the species. This means that in order to have large biodiversity there should be many different kinds of ecosystems, where each consists of several species and every species have genetic variation [13]. Nature's contribution to people comes in different forms, such as providing food, energy or materials and services such as air and water purification, pollination and climate regulation [58, 59]. These services depend strongly on the biosphere's well-being and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) states that biodiversity in all its forms is declining rapidly, induced by both direct and indirect drivers, most of them anthropogenic. The largest direct drivers are land use change and exploitation of organisms, followed by climate change, pollution and invasion of alien species. Indirect drivers are aspects related to societal values and behaviours, such as production and consumption patterns, human population changes, trade and technical innovations. The IPBES further states the need of transformative changes across all sectors to meet both the UN 2050 Vision for Biodiversity and the SDGs [58].

The first EU legislation on the environment is the Birds Directive on the protection of wild bird species in the EU adopted in 1979 and amended in 2009 [60]. The Habitats Directive adopted in 1992 establishes the Natura 2000 ecological network of protected areas to conserve rare, threatened or endemic species, and the Birds and Habitats Directives together constitute the cornerstones of the European nature conservation policy [61]. The EU Biodiversity Strategy from 2020 addresses biodiversity loss and expresses the EU to lead the way by example and by action, putting biodiversity "on the path to recovery by 2030" towards the ambition of ensuring that "by 2050 all of the world's ecosystems are restored, resilient and adequately protected" [59]. The strategy proposes commitments on nature protection and nature restoration and underlines the need for joint efforts to enable necessary transformative changes [59].

2.2.3 Land use and land use change

Agriculture and forestry fall under the sector of LULUCF, which differs from other sectors as it both emits and removes CO_2. Thus, it can act as a carbon sink and contribute to both the EU GHG emissions reduction target as well as to the climate goals of the Paris Agreement [62]. In the EU, the LULUCF sector offsets 7% of the other sectors' GHG emissions [63]. However, the sector strongly impacts biodiversity and ecosystem services why sustainable management is imperative [62].

To maintain the balance between goals for food production and biodiversity conservation, there are two different land use strategies, land sparing and land sharing. Land sparing is when land is set aside for nature conservation and the agricultural production is high-yielding with relatively lower biodiversity. Land sharing on the other hand is when nature conservation is integrated with agricultural production, where the farmland is low-yielding but higher in biodiversity and there is less land uniquely used for nature conservation. Both approaches receive critique for being too narrow and not taking enough factors into account and there is an ongoing debate on whether to use land-sparing, land-sharing or something in between [64]. While land-sparing is associated with monocultures and intensive use of pesticides, some argue that the conservation of land is more beneficial for biodiversity preservation than land-sharing. On the other hand, land-sharing is more used in small-scale farming which some mean is more important for global food security than large-scale monocultures [65].

Other topics that emerge in the bioenergy discussion are direct land use change (dLUC) and indirect land use change (iLUC). dLUC is when biomass cultivation for energy purposes replaces the earlier use of the land and iLUC is when the bioenergy feedstock production displaces cultivation for food and feed purposes to other land, e.g. forests. When this displacement occurs on land areas high in carbon, like forest, wetlands and peatland, GHG emissions are incurred that might undermine the savings from the biofuel itself [14, 66]. In the EU, this aspect is included in the RED II and biofuels are categorised into low and high indirect land use change-risk fuels [14].

2.3 Advantages and disadvantages of bioenergy

There are both advantages and disadvantages of bioenergy, where each one could make up a whole dissertation since what is an advantage or disadvantage largely depends on one's standpoint regarding biomass cultivation. Thus, this section aims to briefly introduce some of the most prominent documented advantages and disadvantages, along with notions that can be either or depending on the context.

Starting with the advantages of bioenergy the most prominent is the ability of biomass and its derived products to substitute fossil alternatives [67]. In an energy system context, an advantage lifted of bioenergy is its storability meaning it can be used whenever it is needed making it a reliable, stable option compared to other renewable sources that tend to be more variable, even if they naturally have other advantages of their own [24]. Another advantage is the national potential of bioenergy production meaning Sweden could possibly become self-sufficient on bioenergy in the future [12]. Moreover, an advocated advantage is the prospect of net negative emissions by BECCS, as mentioned in Section 2.1.2, which is related to the ability of biomass to absorb carbon and act as a carbon sink. Expanding biomass production can lead to an increase in carbon absorption [12], if managed in a sustainable manner which leads into the following paragraph.

In the grey area between advantages and disadvantages comes the question of bioenergy being carbon neutral or not as well as the issue of water use. Starting with the issue of carbon neutrality, it can be addressed from different points of view where all can hold valid arguments, which is the reason scientist have diverging opinions on the matter [68]. During combustion of a fuel, CO_2 is released no matter if the fuel is biogenic or fossil. If looking at the combustion in itself, bioenergy releases up to four times the amount of CO_2 emissions per energy unit produced compared to natural gas, due to its lower heating value. Thus, those critical to biomass will claim it is not carbon neutral as it can take decades for biomass to regrow and absorb an equivalent amount of carbon [69]. On the other hand, those in favour of bioenergy will claim it is carbon neutral stating the biomass have absorbed an equivalent amount of carbon during its lifetime and pointing to the biomass production's capacity of storing carbon and being a carbon sink in the longer perspective. In a policy context, carbon emissions from bioenergy are accounted as carbon neutral as they are excluded from energy sector reporting.

This is to avoid double-counting since the LULUCF reporting to the United Nations Framework Convention on Climate Change (UNFCCC) already takes biogenic carbon emissions into account [70]. Additionally, in Sweden fuels and electricity produced from bioenergy or biomass-derived products are exempt from tax on both CO_2 and energy [71, 72] and the Swedish forest is considered a carbon sink, despite the production outtake, as mentioned in Section 2.1.1.

Moving to the issue of water use, bioenergy can provide both advantages and disadvantages. The types and extents of bioenergy impact on water use and quality differ between different bioenergy systems and highly depend on the local context. When using residues and byproducts from agriculture or forestry for bioenergy, land and water use is lower than when growing for dedicated energy crops. However, the removal of residues must be done in consideration with maintaining soil carbon and a high soil to minimise erosion. Bioenergy crops can on the other hand be used to prevent erosion and flooding by increasing the soil quality. Efficient water management techniques can be used in bioenergy systems and together with cultivation of dedicated energy crops on land not suitable for other uses it can improve water productivity and accessibility. Some disadvantages are competition for water in water scarce area, reduced water accessibility downstream and impact on water quality from e.g. fertilisers. The aspects of water use are essential in sustainable management of bioenergy systems to avoid or mitigate negative impacts [73].

Turning to disadvantages, combustion of biomass for energy inevitably generates CO_2 emissions at the plant as well as emissions of other pollutants such as particulate matter, volatile organic compounds and nitrogen oxides (NO_x) that can impact the local environment [74]. This can be compared to solar and wind power that have zero emissions once they are constructed. However, the aspect of time is important in the evaluation of bioenergy potential. For example, forest residuals burned in an energy facility will release carbon earlier than if they were to be left in the forest, even though the amount of carbon emitted to the atmosphere will eventually be the same. From a short time perspective, bioenergy can thus be disbenefited [66]. Another time aspect is when bioenergy expansion generates increased GHG emissions due to LUC since these emissions occur in the near-term and thus net savings from replacing fossil fuels come in the longer perspective. The issue of whether GHG emissions from LUC undermine the climate change mitigation benefits of bioenergy is much-debated and is an aspect in need of consideration. Berndes [66] suggests several ways of taking LUC emissions into account to ensure sustainable bioenergy, such as certification on bioenergy avoiding undesirable LUC, assigning a certain level of LUC emissions to bioenergy options and support for low LUC-risk bioenergy options.

While bioenergy is a key aspect in energy security, the land requirements inevitably evoke the question of food security. The Food and Agriculture Organization of the UN has set up a series of good environmental and socio-economic practises as well as policy instruments supporting these practises in order to ensure both energy and food security [75].

Another debated disadvantage is the impact bioenergy production systems has on biodiversity and ecosystem services. The main drivers for biodiversity loss connected to bioenergy are LUC followed by direct exploitation, e.g. via harvesting or logging, and the extent depends on previous land use, which production system is used and how it is managed [58]. In Sweden, agriculture and forestry stand for the biggest pressure and threats for habitats and species [76]. Connected to biodiversity is the aspect of monocultures which are prevalent in both agriculture and forest production systems. While forest monoplantations can reduce the pressure on natural forests by providing forest products and rehabilitate degraded landscapes, the single-species plantations are at higher risks of pests and diseases and have lower biodiversity than natural forests due to e.g. clearcutting and poor habitat provision [77].

To end this section, it is important to note that the possibilities for bioenergy are different around the globe, meaning there is no universal solution on how to best use bioenergy.

2.4 Environmental policy instruments

A policy instrument is a tool used to achieve a desired outcome, generally in economic terms. They aim to correct so-called market failures, which occurs when a competitive market does not generate an optimal use of resources, either in social, economic or environmental terms. This thesis focuses on environmental policy instruments, which are tools mainly used by governments where the desired outcome is positive environmental effects. The common goal of environmental policy instruments is internalising environmentally harmful externalities such as pollution and emissions in order to move closer to socially optimal levels of pollution and abatement [78].

An important concept in regards to environmental policy instruments is the polluter pays principle. This means the actor causing the pollution, the polluter, is responsible for all emissions and has to pay both for reducing emissions and for the remaining emissions. The goal of instruments applying this principle is to incentivise actors to reduce their emissions and encourage clean practices and innovation of new technologies [78]. In the following subsections, different environmental policy instruments are introduced with regards to characteristics, after which current policy instruments relevant to the energy industry and bioenergy production in Sweden and the EU are presented. This section provides the foundation upon which the policy landscape presented in Section 4.2 is based.

2.4.1 Overview of environmental policy instruments

There are many types of environmental policy instruments and different ways of classifying them. One way of classification, as made by Sterner and Coria, is shown in Table 1, where four main categories are identified; using markets, creating markets, regulations and engaging the public [78]. The significance of each is discussed below.

Table 1: *Overview of different types of policy instruments. Table adapted from Sterner and Coria [78].*

Using market	Creating market	Regulation	Engaging the public
Taxes	Tradable permits/quotas	Laws and regulations	Public participation
Subsidy reduction	International offset systems	Performance or technology standards	Information disclosure
Charge, fee/tariff	Property rights	Ban	Liability
Deposit-refund, refunded charge	Common property resources (CPR)	Permit	Voluntary agreement
Targeted subsidies	Certificates	Zoning	

The first column presents policy instruments **using markets**, meaning instruments that adjust prices on an existing market to internalise externalities. These are also known as price-based instruments, since they set the price of pollution and/or abatement whereas the levels of abatement and quantities produced are more uncertain. The typical example is taxes, which in environmental context normally are carbon or CO_2 taxes. Other examples are subsidy reduction, where a subsidy of an environmentally harmful practice is removed. It could also be a charge, fee or tariff on environmentally harmful practices or goods. These charges can be refunded when the good is disposed of correctly or if the practice is executed more environmentally friendly than necessary, commonly known as refunded emissions payment (REP). Moreover, targeted subsidies on green technology innovation or pollution abatement can be implemented to create an incentive for environmentally friendly behaviour. One advantage of policy instruments using markets is the price-fixing since this prevents the costs from rising unrestrainedly in case of steep cost developments. One disadvantage is the political opposition linked mainly to taxes and subsidy reductions, rising partly from fossil lobbies but partly also from civilians.

Policy instruments **creating markets** are to some extent the opposite of those using markets. In creating markets, a cap is set on either emission levels or quantities produced in order to decrease harmful externalities. This fixates the quantity but leaves uncertainty of the costs of abatement, why these instruments are also called quantity-based. Thus, these policy instruments allow a new market to emerge. The typical examples are tradable permits or quotas, so-called cap and trade schemes, where trading between different producing actors, i.e. companies or countries, occurs after emission permits have been allocated. There are different ways of allocating permits. A certain amount of permits can be allocated for free, where the actor can sell their excess permits or buy additional ones depending on their situation during the trading. This is called grandfathering and is the most common allocation today. The amount of free permits per actor can be based on either historical emissions or output quantities. Another way of allocating permits is auctioning. In this case, the actors have to buy all the permits they need for their emissions, making it similar to a tax from a cost-perspective. Auctioned permits are thus placing more responsibility on the actors for their emissions compared to grandfathering. Further, there are international offset systems, where a country can profit from reducing emissions in other countries. Other examples of policy instruments creating markets are assigning property rights of the environmental externalities to designate responsibility and common property resources where resources are owned together by a community, which handles externalities by internal rules. Moreover, certificates assuring environmentally friendly practices enables markets where consumers can make more conscious choices. Certificates can be both voluntary or mandatory but a common denominator is the third party audit.

The third column presents **regulations** treating environmentally harmful externalities. This includes laws and other direct regulations, and technology and performance standards. Technology standards regulate which technology can be used and performance standards what levels of emissions or output quantities are allowed. It could also be banning of or permit to use some amounts of harmful practices or substances. Another example is zoning, where areas of land are divided into zones inside which certain rules apply. This can be either zones of environmental protection or zones where only clean technologies are allowed.

Lastly, policy instruments **engaging the public** are as the name suggests focusing on the public, i.e. society. One way is to involve people to participate in environmentally friendly behaviour in order to reduce harmful externalities. Another way is information disclosure, where companies and/or countries transparently report their sustainability work towards the public. There can also be legal aspects such as liability, where companies are held accountable for the potential toxicity or harmfulness of their practices. Finally, voluntary agreements are instruments without requirements where producing actors can choose to participate in creating a good image of environmentally friendly behaviour, and which can generate labels further helping the image.

2.4.2 Policy instruments in Sweden

Sweden has an ambitious goal of becoming the first fossil free welfare nation in the world, having zero net emissions already by 2045, compared to the European goal of 2050 [79]. To enable this, several environmental policy instruments contribute, some implemented recently and some many years ago.

Climate laws and goals of a fossil free transition

The goal of a fossil free Sweden by 2045 is along with some intermediate targets part of the Swedish climate policy framework, which entered into force in January 2018. In addition to the climate goals, the framework includes a climate law and a politically independent, interdisciplinary expert body, the Swedish Climate Policy Council. The law binds all Swedish politicians to work in accordance with the climate goals and aims to combine ecological sustainability, competitiveness and security of supply. The Council consists of people with high scientific competence in relevant areas, with the role of assisting and evaluating the government in their climate work [79, 80]. Further, the government is required to present a climate report each year along with the budget proposal as well as an action plan for climate policy every fourth year [6]. The first action plan for climate policy was presented in December 2019 and the reply from the Swedish Climate Policy Council came in March 2020. The plan presents 132 action points towards achieving the climate goals but the Council emphasises in their report that these are not enough. In their assessment, the action plan is not specific enough, has no courses of action nor any distribution of responsibility and accountability [43, 81].

In January 2020, Sweden delivered a National energy and climate plan (NECP) by order of the EU, which can be viewed as an information disclosure type of instrument. It addresses Sweden's plan for reaching the targets for 2030 defined in the EU 2030 climate & energy framework (see Section 2.4.3) and presents intentions concerning energy efficiency, renewable energy share, GHG emissions reductions, interconnections as well as research and innovation [82]. The plan is based on the Swedish climate policy framework and goals. It defines which are the intermediate targets, presents some context and adds some suggestions on how to achieve the goals. There is a strong focus on the importance of an open, competitive market for finding the most cost-efficient solutions regarding both technology options and distribution logistics [79]. One significant aspect lifted in the Swedish NECP is the message that it is possible to combine climate change mitigation with social welfare and strong industrial competitiveness. This is also the main argument for Fossil free Sweden [7, 79], which has been used to enhance the agreement between the different industrial sectors trade organisations in creating roadmaps on how to achieve the Swedish climate goals, as mentioned in Section 1.1.

At the core of Swedish climate legislation resides the Environmental Code [83], which is a direct regulation in the form of a law. When it entered into force in January of 1999, it collected the 15 previously disperse environmental legislations and united them into one overarching Code, which facilitated law-abiding [84]. In the Environmental Code, the aim is stated as "promoting sustainable development which includes current and future generations are ensured a healthy and good environment", where it is further stated that this development needs to be founded in "the realisation that nature has a protective value and that humanity's right to change and use nature is associated with a responsibility to manage nature well" [85], which conforms with the concept of environmental sustainability presented in Section 2.2. The Environmental Code consists of seven divisions where parts 2 *Nature conservation* and 3 *Regulations on specific operations* are of most relevance for this thesis; the others mainly state definitions and legal consequences. *Nature conservation* includes the protection and conservation of valuable natural and cultural environments and preservation of biodiversity. *Regulations on specific operations* includes environmental and societal protection from hazardous operations and contains specific directives on agriculture and waste treatment amongst other sectors. In addition, another application of the Environmental Code is to enable "re-use and recycling as well as other conservation of material, resources and energy are promoted to achieve circularity" [85].

Taxes and energy-related policy instruments

Taxes have long been well-integrated in Swedish governing policy, appearing at the same time as the state of Sweden when people united under one king, possibly as early as the 11^{th} century [86]. The Swedish king Gustav Vasa played an important role in shaping Sweden in the 16th century by organising and controlling the Swedish finances as well as converting Sweden to Protestantism, plundering the churches of silver and adding them to the taxpayers. Under the reign of one of his grandsons, the people of Sweden were divided into taxpayer groups with different obligations, creating a principle of classification that remained until the 20th century [86]. Hence, it is no wonder one of the most important environmental policy instruments in Sweden today is a tax; namely the CO_2 tax.

The Swedish CO_2 tax is the highest of its kind in the world and was established in January 1991, making it also one of the oldest in the world. At this time, the CO_2 tax was differentiated from the energy tax [87]. Both taxes comprise fuels for heating and propulsion and the energy tax includes also electricity and energy products aimed for heating and propulsion [71]. The energy tax on electricity is fixed for all uses whereas the tax rates of CO_2 and energy differ depending on the type of fuel and area of use. For 2020 the tax rate for electricity is 0.353 SEK/kWh consumed electric power [72]. The 2020 tax rates of CO_2 and energy for heating oil, coal and natural gas for non-transport use are presented in Table 2 [88].

Table 2: *Tax rates in SEK/1000 m^3 for 2020 of CO_2 and energy for heating oil, coal and natural gas for non-transport use. Table adapted from the Swedish Tax Agency [88].*

	Tax rates [SEK/1000 m^3]	
Fuel type	*CO_2*	*Energy*
Heating oil	3420	903
Coal	2976	687
Natural gas	2561	998

To put the Swedish CO_2 tax in a European perspective, in 2019 the tax corresponded to over 112 euros per tonne CO_2 equivalents where the runner-up Switzerland had their tax at 83 euros and the lowest being Poland with 0.07 euros [89].

Electricity produced from renewable sources is exempt from the energy tax. This applies to, inter alia, biomass or products derived from biomass, solar and wind power. It is also possible to apply for tax exemption for certain uses of electricity, e.g. consumption from trains and other rail-bound transport means [72]. Previously, renewable fuels such as biogas, ethanol and biodiesel were exempt from the CO_2 and energy taxes, but in July 2018 a new system entered into force, the so-called Reduction obligation (reduktionsplikten) [90]. The obligation is a performance standard that aims to increase the share of renewable fuels by obliging fuel suppliers to gradually mix in more renewables into petrol and diesel to finally reach the national goal of 70% decreased GHG emissions from domestic transport by 2030 [91]. Biogas and other pure or high-mixed biofuels are still exempt from the CO_2 and energy tax [90]. However, this could change with the revision of the EU State Aid rules by the turn of 2020 that will be stricter on food-based biofuels. Sweden thus needs to re-apply for exemption from the European Commission. If they refuse, this would drastically increase the cost of biofuels [92]. In the spring of 2020, the Swedish government applied for prolonged Aids for the current tax exemption of biofuel as well as for biogas used in heating and as motor fuel [93]. In June, the Commission approved the tax exemption on biogas for heating and motor fuel for the coming 10 years with the modifications of limiting to only non food-based biogas and extending it to also include non food-based biopropane [94]. As for biofuels, both food-based and non food-based, the verdict is yet to be announced.

A State Aid is defined by the European Commission as “an advantage given by a government that may provide a company with an unfair competitive edge over its commercial rivals”[95], meaning it promotes products or companies receiving the Aid thus distorting the open competitive market [96]. To prevent this, especially between member states, the Commission ensures national State Aids conforms with the EU rules [95]. In fact, the rules prohibit State Aids unless they can be proven to “promote general economic development, for example, when tackling the challenges of global competition, the ongoing financial crisis, the digital revolution, and demographic change”, in which case the Commission has to approve the Aids before they can be implemented. Despite this, most member states do provide State Aids to promote their own economy [97]. The rules on State Aids were first established in 2007 covering the period up until 2020, why a revision and modernisation of the State Aids is under development where the EU calls for less and more targeted State Aids in the future [97]. For biofuels specifically, the EU wishes to redirect the production away from food crops, such as sugar beats and rape seeds, into second generation biofuels, i.e. from waste and residues [92]. In a more general Swedish perspective, the EU rules on State Aids have advanced Swedish competitiveness by revoking 14 million euros in unauthorised Aids from various member states during the past ten years [98].

Returning to taxes, a tax on waste incineration entered into force on the 1st of April 2020. The aim is to enhance the so-called green tax exchange to achieve a more effective and non-toxic waste treatment. The starting price is set to 75 SEK per tonne waste, which will be step-wise increased to 125 SEK/tonne by 2022 [99]. Note that before the implementation, the Governments Official Investigations made an investigation in 2017 on whether or not emissions from waste incineration should be taxed (SOU Brännheta skatter), where they stated such a tax would not generate the desired effect since it would not affect those responsible for generating waste [96]. Moreover, since June 2020, waste in the form of recycled wood is exempt from this tax and instead considered bioenergy [29].

Other policy instruments that have been important for the energy industry are the NO_x charge and the electricity certificate system (elcertifikatsystemet). Starting with the NO_x charge, it has enabled a reduction of Swedish NO_x emissions by half between 1990 and 2018 [100]. When implementing it in 1992, the aim was to reduce NO_x emissions from power plants by creating economic incentives to reduce emissions, which has been done mainly by the implementation of flue gas treatment [101]. Today, plants with production over 25 GWh are included in the scheme and the charge is at 50 SEK/kg of NO_x, which was last increased in 2008. The charge is built in a REP manner, where all charges are collected to a common fund that each year allocates a sum back to the power plants. The amount depends on the plants’ specific amount of emissions in kg_{NO_x} per MWh [96]. Concerning the electricity and DH sector, their NO_x emissions in absolute terms do not show a decreasing trend in the period 1990 to 2018. The specific emissions however do [96]. NO_x emissions from electricity and DH account for a small share of the total Swedish emissions and the amount is lower in 2018 than 1990 even though the fuel supply to the plants have more than doubled during the same period [100]. The same reasoning is true for waste incineration. In fact, waste plants are the winners of the REP system [96]. The same investigation concerning tax on waste incineration also treated the question of whether it would be desirable to transform the NO_x charge into a tax. The investigation does not suggest whether or not to transform, as it states that it is a highly political question. The investigation finds that the transformation to a tax would drastically increase costs for all affected plants which could hurt Swedish competitiveness, and increasing the current charge or including more sectors might collide with the EU rules on State Aids. However, since the NO_x charge was already implemented when Sweden entered the EU in 1995, it is considered as an existing Aid and is as such allowed [96].

Turning to the electricity certificate system, which is also known as green certificate system or renewable certificate system, it was established in 2003 with the aim of increasing use and production of electricity from renewable sources by offering support to compete with non-renewable energy sources [102]. The system entitles new green plants, such as bioenergy-fueled CHP or wind farms, to electricity certificates for 15 years, which works as a production subsidy for energy from renewable sources [96]. The system entails the goal of a yearly increase in renewable energy. The amount to be achieved has been step-wise increased and was altered in 2015 to 28,4 TWh by 2020 compared to the amount in 2002 [102]. In 2017, the Government prolonged the system to 2045 with the goal of an additional increase of 18 TWh by 2030 [103]. However, in June 2020, a stop date for the electricity certificate system just finished its referral round. The proposition is to end new applications for electricity certificates by the end of 2021 thus terminating the system already by 2035, as it is deemed the goals will be reached already [104].

Forest policy and nature conservation

As previously mentioned, Swedish forests account for 70% of the land area [16], why forest policies are essential when treating Swedish bioenergy potential. Sweden has a long history of forestry and forest policies, with documentation from as early as the 12^{th} century. In 1647, what can be considered the first Swedish forest regulation was published, which stated, inter alia, that on the Crown's land it was forbidden to burn down forests for agricultural fields and that for each tree felled, 2-3 new ones had to be planted [105]. By the end of the 19^{th} century, the forest growth was endangered by the past century's intense logging. At this point, the Government realised they had to intervene, why the Swedish Forestry Act was established in 1903. It is Sweden's first nation-wide forest policy and the oldest of its kind in the world [106]. The Forestry Act regulates acceptable forest management practices and states which obligations forest owners have. The Swedish Forest Agency (Skogsstyrelsen) describes that "the law states that the forest is a renewable resource that is to be managed sustainably yielding a good revenue. At the same time, you must take consideration of nature, cultural heritage, reindeer husbandry and other interests"[107].

Side by side with the development of forest policies, environmental organisations appeared. Sweden's today largest and most influential environmental organisation Naturskyddsföreningen was established in 1909 and required already in 1943 a ban of clear-cutting [105]. After a heated debate on clear-cutting in the 1970s driven by various environmental organisations, the Forestry Act was eventually altered to equalise production and environmental goals in 1994 [108]. Today, the Swedish model of forest management is often summarised as "freedom under responsibility", meaning forest owners have the freedom to manage their forests according to personal goals while still being obliged to fulfill all forest policy goals [17]. Naturskyddsföreningen is a non-profit member-organisation with the focus of highlighting environmental issues and ensuring action [109]. For example, Naturskyddsföreningen contributed to the foundation of the Swedish Environmental Protection Agency (Naturvårdsverket) in the 1960s, something they had promoted since 1935 [110]. Today, Sweden has elaborate nature conservation and extensive environmentally protecting legislation.
Moreover, there are international voluntary agreements where forest owners can apply for certification

of their forestry to ensure its sustainable management practices, such as the Forest Stewardship Certification (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). The certification is either on the forest management or the chain of custody, where the latter covers the production process from forest to consumer, and they all aim to promote sustainable forest practices by proving compliance with regulations as well as ecological and social sustainability measures. With the certification, wood and other forest products can be sold as “sustainably produced” which gives access to certain markets and attracts conscious consumers [111]. The environmental movement pushed for the creation of FSC in 1993 as an answer to deforestation of tropical forests, and PEFC was created in 1998 by several north European countries to enable the creation of national standards adapted to local conditions and to facilitate certification for small-scale forest owners. In 2000, several Swedish actors created the Swedish PEFC standard which was approved by the international PEFC council later that year [112]. While FSC and PEFC are primarily applicable to forest-based products, the Roundtable on Sustainable Biomaterials (RSB) provides a certification scheme that “covers the production of any bio-based feedstock, biomass-derived material and any advanced fuel and material, as well as complete supply-chains and novel technologies”, and this standard has an EU RED version that verifies complicance with RED II [113].

Even if the Swedish model of forest management is often praised, it has many opponents. For instance, 70 environmental organisations and 30 scientists from 25 countries united in an appeal to the Swedish Government in February 2020, where they criticise the lack of habitat protection and call for abolishment of felling high natural value forests and a phase-out of clear-cutting once and for all [114]. On the same note, the European Commission highlighted in May Swedish infringements on EU laws concerning conservation of natural habitats and protected species, where they state Swedish actions as insufficient [115].

Agricultural policies and support schemes

When it comes to agricultural policies, Sweden is mainly governed by the EU Common Agricultural Policy (CAP), which aims to stimulate the European agricultural sector in food production and farmer conditions [116]. For bioenergy derived from the agricultural sector, the RED II dictates sustainability criteria, as mentioned in Section 2.2.1.

Swedish farmers can apply for different support schemes promoting bioenergy production, either farm support (gårdsstöd) for growing energy forests such as salix or poplar [117] or support for producing biogas from manure (gödselgasstöd) [118] along with additional biogas support if it is aimed as biofuel, i.e. to the transport sector (biogasstöd) [119]. Note that these are pure farm supports which does not directly influence the energy sector. However, they can lead to increased production of bioenergy crops and energy forests.

Also in the energy sector, it is possible to apply for support schemes. In 2015, a targeted subsidy for local and regional climate mitigation actions was established, the so-called Klimatklivet [120]. Actions and measures to reduce emissions and/or climate impact can receive support, which was altered in 2019 to apply only to physical actions and no longer to actions enabling behavioural change. Also, actions induced by law, regulations or other governmental decisions do not qualify for support. For the energy sector specifically, supports can be granted for energy efficiency measures, development and expansion of renewable energy or energy-efficient district heating and cooling systems [121]. The size of the available support is decided by the Government in the national budget [120].

Final comment on Swedish policy instruments

To conclude this chapter on Swedish policy instruments, it can be noted that in many aspects, Sweden is perceived as a leading country. In several aspects, Sweden has been ahead of time, one being the implementation of the CO_2 tax as mentioned above, another being strict regulations concerning antibiotics use in farming. Sweden was the first country to ban antibiotics in fodder in 1986, something the EU banned several years later, in 2006 [122]. Also when it comes to the fossil free transition, Sweden is at the forefront. For example, the EU requires all member states to have a 32% share of renewable energy by 2030, something Sweden already surpasses: today the share is approximately 50% and the forecast to 2030 is 65% [79].

2.4.3 Policy instruments in the European Union

As previously stated, the EU objective is to be climate neutral by 2050 and therefore there are many laws, regulations and other policy instruments coming from the EU to help the member states reach this target [123]. The EU law is divided into primary and secondary law, where primary law is made up of treaties which are binding agreements between member states, setting out "EU objectives, rules for EU institutions, how decisions are made and the relationship between EU and its members" [124]. Secondary law can only be passed in areas addressed in the treaties and constitutes of regulations, directives, decisions, recommendations and opinions. Regulations are directly binding to all EU countries whereas decisions are directly binding only to whom they are addressed. Directives set out objectives and are to be transposed into national law, but member states are free to choose the manner of achieving the objectives. Recommendations and opinions have no binding force, but allow the EU institutions to express views, suggestions of action or statements [124].

To ensure sustainable future development, the European Commission has set binding targets on GHG emissions reduction, renewable energy share and energy efficiency improvement compared to 1990 levels in both the 2020 climate & energy package (20% for each) until 2020 and the 2030 climate & energy framework (40%, 32% and 32.5%) for the period 2021 to 2030 [125]. The commission recently finished the public consultation on the incentive impact assessment for the 2030 Climate Target plan that is to be adopted in the third quarter of 2020 and aims to increase the GHG target to at least 50% reduction, striving towards 55%. As a part of this, the commission will propose by June 2021 required updates on current climate policies, such as the directives on emissions trading system (ETS), energy efficiency and renewable energy (RED II) as well as effort sharing and LULUCF regulations [126]. Since the EU started the European Green Deal in 2019, there are two climate actions already in place. The European Climate Law puts the climate neutrality by 2050 target into legislation and the European Climate Pact is a platform for inspiration and cooperation between people and organisations in all parts and levels of society [123].

European trading system and effort sharing

One of the fundamental policy instruments in the EU to reduce GHG emissions is the EU ETS, an instrument creating markets with tradable permits. It entered into force in 2005 as a result of developing a policy instrument to incentivise the reduction targets set by the Kyoto Protocol in 1997 [127]. The ETS is a cap and trade system between all EU countries as well as Iceland, Liechtenstein, Norway [128] and from 2020 also Switzerland [129]. The emissions covered are CO_2, N_2O and PFCs from power stations, industrial plants and airlines between these countries. A cap is set on total emissions from the system by the EU and this cap is successively reduced to obtain lower emissions. At the start of each year, some allowances are allocated to the companies by grandfathering, where one allowance is worth one tonne of CO_2 or the equivalent of N_2O or PFCs. If the free allocation does not cover the company's planned emissions, they can buy more through auctioning. During the year, companies can trade with each other to manage increases or reductions in emissions [128]. Thus, the price per allowance is set by the market and is currently at approximately 25 euros per tonne CO_2 [130]. In the early years of ETS, all allowances were given for free and the penalty for non-compliance was 40 euro per tonne CO_2 [127]. Over the years, the share of free allowances has decreased and the penalty increased, where today with the ETS currently being in its third phase, 43% of allowances are given for free [131] and the penalty is 100 euro per tonne CO_2 [127]. However, the number of free allocations vary between sectors, and the electricity sectors have received no free allowances since 2013 [131].

As the third phase of the EU ETS is approaching its end in 2020, a revision for the fourth phase (2021-2030) was made in 2018, in order to reach the 2030 emission reduction targets. During this fourth phase, it is foreseen the free allocations will be gradually eliminated between 2026 and 2030, although saving free allowances for so-called new and growing installations as well as industries at high risk of relocating production out of the EU [132]. As a part of the 2018 revision, two new funds were implemented to encourage and enable innovation and modernisation towards low-carbon power and industrial sectors, the innovation fund and the modernisation fund [132]. The innovation fund consists of revenues from the auctioning in the EU ETS and is a funding program with a focus on innovation in low-carbon technologies such as CCU, CCS, renewable energy generation and energy storage [133]. The modernisation fund is applicable in 10 lower-income member states and promotes investments in modernisation of the power sector [132]. Both the funds work as targeted subsidies.

Not all sectors are included in the EU ETS system, such as transport, buildings, agriculture and waste. For these sectors, there are binding annual targets on GHG emissions in the Effort Sharing Regulation. The targets are set by the EU for each country based on GDP per capita, and the contribution from all countries will end up in a 10% reduction by 2020 and 30% by 2030, compared to 2005 levels [134]. Each member state is responsible to implement sufficient measures and policies to reach their targets and there are certain flexibilities in the regulation to ensure that the achievement of targets is fair and cost-effective. Member states are allowed to bank surplus emissions or borrow from the following years as well as buying and selling allocations from and to other countries. They might also access credits from the land use sector and nine member states are permitted to use a maximum of 2% of ETS allowances to offset emissions in the Effort Sharing sectors. Sweden is one of the nine and has decided not to use this last flexibility [135]. While the EU ETS covers only CO_2, N_2O and PFCs, the Effort Sharing includes all six GHG covered by the Kyoto Protocol, an international voluntary agreement from 1997, meaning CO_2, N_2O, CH_4, HFCs, PFCs and SF_6, as well as NF_3 [134].

Forest policy and sustainable biomass production

Emissions from land use, land use change and forestry (LULUCF) are neither covered by the EU ETS nor the Effort Sharing Regulation, since forests and agricultural lands have the peculiar capacity of carbon sequestration. Thus, emissions need to be looked at together with the removal of CO_2 from the atmosphere as well as storage in biomass and soils and this principle is known as the "no-debit rule". This is covered by the Kyoto Protocol until 2020 by compensating emissions with the absorption of CO_2 [136] and in 2018, the European Commission included LULUCF in the 2030 climate and energy framework by means of the LULUCF Regulation in order to account for these emissions in reaching the targets during the period 2021-2030 [62].

The use of renewable energy in the EU is specified in RED II [14], which states a binding Union target of at least 32% renewable energy sources in 2030 as well as how these sources are to be used for electricity, transport, heating and cooling. As mentioned in Section 2.2.1, it provides sustainability criteria for biofuels, bioliquids and biomass fuels, and it further establishes GHG emissions saving criteria for these said fuels. Furthermore, it describes cooperation between member states and with third countries as well as administrative procedures and information. The compliance with the directive is ensured by the implementation of guarantees of origin for energy from renewable sources in each member state and the directive is to be transposed into national law by the 30^{th} of June 2021 [14].

There are several voluntary certifications available to ensure compliance with the EU sustainability criteria when producing bioenergy feedstock, for example the International Sustainability Carbon Certification and the previously mentioned RSB EU RED Standard. The certifications make sure that the bioenergy feedstock production neither intrudes on land with a high amount of carbon nor on land with high biodiversity and that it leads to GHG emissions savings [137]. As mentioned in Section 2.2.2, the Birds and Habitats directives together with the 2030 Biodiversity strategy provide a framework for nature conservation and restoration.

Energy efficiency

The current energy efficiency target of 32.5% reduction by 2030 is set in the amending Energy Efficiency Directive (EED) from 2018, which is accompanied by several binding measures to reach this target. The directive allows the target to be revised upwards in 2023 if economic or technological developments cause significant cost reductions [138].

2.5 Future aspects

As the Danish physicist and Nobel laureate Niels Bohr said, “predictions are hard, especially about the future”. However, predictions, prognoses and future scenarios are key aspects of the fossil free transition. There are several reports on the topic of future prospects, and this section briefly presents some of them.

To begin with, the Swedish Energy Agency has created four possible scenarios of the future energy system in Sweden based on which role energy will have in society, which is strongly linked with societal development [139]. In the first scenario, industry is strong and focus is on low energy prices and economic growth. The second scenario promotes ecological sustainability and a fair distribution of resources. The third advocates flexibility and local solutions whereas the fourth and last scenario aims for innovation and technology as a means of mitigating climate change. The conclusions from all scenarios are, amongst others, that policy instruments are necessary to promote desired technologies, that the future energy system will be more diversified and that Sweden is strongly affected by what happens in the rest of the world [139].

Secondly, as previously mentioned, several industrial sectors have published roadmaps under the initiative Fossil Free Sweden on how to continue the fossil free transition. In these, the possibility of reaching fossil free welfare by increased efficiency, the substitution of fossil fuels with biobased alternatives, reduced energy demand and shaving of energy demand peaks is stated [140]. In addition, they state this requires political action, such as long-term decisions and support that reduces the risk of investing in new technologies and a green taxation reform that promotes the competitiveness of the green sectors [141].

Furthermore, as mentioned in Section 2.1.2, the Governments Official Investigations presented a report in 2020 on the pathway towards a carbon-positive future, which presents a strategy and an action plan to reach to Swedish 2045 targets [39]. To do this, emission reductions as well as complimentary actions are stated as necessary. For emission reduction, they state the use of fossil fuels needs to be dismantled. For complimentary actions, efforts to increase carbon sequestration in forestry and agricultural production are suggested as well as carbon removal by both CCS and BECCS. Similar to the requirements of the roadmaps by Fossil Free Sweden, this investigations state long-term decisions and support are needed to create stable conditions for complimentary action projects.

In many scenarios, several sectors requires biomass as part of the solution to achieve net zero emissions. With this comes the question of whether it is possible to sustainably supply all the biomass needed. With regard to constraints such as technical, ecological and economical, Börjesson suggests a potential of increasing the supply until 2050 with 72-92 TWh from forestry (36-50 TWh), agriculture (35-40 TWh) and to a negligible extent even from aquatic biomass (0.1-1.5 TWh) [142]. In the Swedish Energy Agency report on the environmental impact of forest biomass [143], it is possible to increase the outtake of forest residuals and stumps with 27 TWh when the Swedish environmental goals of living forests, toxic free environment, only natural acidification and no eutrophication are considered, which equals half of the forest residuals, given ash return is in place, and 20% of the stumps. However, as mentioned in Section 2.1.1, Naturskyddsföreningen and WWF promote leaving stumps be [21].

Moreover, the Swedish NECP mentioned in Section 2.4.2 notes that the rapid increase in electricity consumption in urban areas can lead to regional capacity shortage. To investigate the risk and plausibility of these kinds of capacity shortages, the Swedish Energy Market Inspectorate was given the task to perform an analysis, the report of which is set to be presented in October 2020 [79]. Finally, there are naturally several other reports treating future prospects which have not been lifted here. For instance, different IPCC reports or EU strategies in the 2030 Climate & energy framework and the Green Deal are not lifted as these have been previously mentioned.

3 Method

This section presents the methodology used in this thesis. First, the choice of research design is introduced, followed by descriptions of literature reviewed and data collection by semi-structured interviews. Further, the data analysis method is presented and lastly, the research quality is described.

3.1 Research design

The research questions in this thesis are broad and open-ended and thus exploratory, why a qualitative research approach is chosen. Qualitative analysis focuses on words rather than numbers and uses an inductive process where observations and findings are analysed in order to draw conclusions and generate new theory [144]. As a key tool in gathering information and future prospects in the subjects of bioenergy transitioning and policy instruments, 25 qualitative interviews with open-ended questions were performed. The questions used as a starting point are found in Appendix A. This type of interviewing is known as semi-structured interviews where there are prepared question and structure but also flexibility of clarifying and elaborating subjects that arise along the interview [145].

3.1.1 Research methodology

Information for this thesis was gathered in several steps through a review of existing literature. The first part consisted of gaining knowledge and finding relevant background information to pinpoint what interview questions were to be asked. In parallel with this, the current situation of environmental policies was investigated. Later on, literature was used to deep dive into areas that emerged during the interviews as a means of elaborating the theory section and providing a foundation for the discussion.

3.1.2 Data collection

In order to find interviewees, purposive sampling together with snowball sampling was used. The first is when the researcher strategically chooses respondents relevant to the research questions and the second is when initial contacts are used to find further respondents [144]. Most of the interviewees were people that our examiner and/or supervisors found suitable for the thesis, others were found by contacting relevant companies or organisations and some were suggested by already interviewed persons. The common denominator is that they all have extensive knowledge in their respective fields and are able to make qualified predictions of the future based on their experiences. The interviewees were categorised into four main groups: energy actors, bioenergy providers, academics and environmental actors. As stated in Section 2.1.1, the bioenergy category also includes waste. Depending on the flow of the interview, different additional questions were asked in regards to the interviewee's knowledge base, background and current employment. The partition of the interviewees into the categories is shown in Table 3 and a list of the interviewees with a description of their roles is found in Appendix B.

Table 3: *Number of interviewees in each category.*

Energy actors	Bioenergy providers	Academics	Environmental actors
7	7	5	6

The interviews were held mostly on video link and if problems arose the video was shut off. Only a minority of the interviews were conducted face to face. The interviews lasted for approximately one hour and we took turns in interviewing and writing down the answers. The notes were taken scrupulously and no audio recording was done. Prior to the interviews, the research questions and a short description of the thesis were sent out and in a few cases, the interview questions were sent out beforehand by request of the interviewee.

3.1.3 Data analysis

The interview data obtained were analysed using the grounded theory methodology, where the key process is coding of the data to break it down into concepts that can be categorised [144]. Coding can be based on either predefined concepts, from theory or overview of the data, or solely on the data, where codes emerge during the coding process [146]. The coding process was done iteratively where the interview notes were first coded based on the content in the statements and put into different categories where some were based on the literature studied and the questions asked, and some arose during the analysis. The same statement was allowed several codes if necessary, resulting in a large matrix of categorised concepts. A second round of categorising followed where each category was evaluated and statements moved around into existing or new categories if needed. The final categories expressed opinions from the interviewees and were in turn categorised based on the research questions. Lastly, a quantification of each category was done to identify the frequency and distribution of the opinions and find where the interviewees agreed and disagreed.

3.2 Research quality

When conducting research, there are important aspects to consider in order to ensure high research quality. There are different ways of approaching qualitative aspects in qualitative research and one way is by discussing reliability and validity from both an external and internal perspective [144]. In addition, ethical aspects should be taken into consideration in each step of the research.

3.2.1 Reliability and validation

The external and internal aspects of reliability and validation as expressed by Bryman and Bell [144] are demonstrated in Table 4.

Table 4: *External and internal aspects of reliability and validity in qualitative research [144].*

	Reliability	**Validity**
External	Degree of replication	Degree of generalisation
Internal	Consistency in the research team	Credibility

External reliability, or replication, is an issue discussed in relation to qualitative research that requires a great deal of transparency [147]. Aguinis and Solarino [147] suggest three different types of replication: exact replication where both the methodology and respondents are the same, empirical replication where the methodology is the same but different respondents are used, and conceptual replication where the same respondents are used with a different methodology. In this thesis, the methodology is described as transparent as possible in the current section and the interview structure together with a list of the respondents are found in Appendix A and B. However, as already mentioned the interviews were semi-structured and follow-up questions were based on the flow of the interview. The answers are also affected by the current situation implying that an exact replication is hard to obtain.

Internal reliability, also referred to as inter-observer consistency [144], equals the way the different persons in a research team observe, handle and judge the data. To obtain this consistency, a continuous dialogue has been held during the analysis to ensure a common view on the coding, categorisation and drawing of conclusions.

External validity and the possibility to generalise the findings are matters to be handled with care in a thesis like this. We are aware that the input gathered from the interviewees together with information collected only represents a fraction of what the future will look like and that there is a big uncertainty in trying to predict the future.

Lastly, **internal validity** signifies the credibility of whether there is consistency between the observations and the concluded findings. One way to handle this aspect is by respondent validation, where the interviewees are given the possibility to confirm that the researchers have correctly understood their opinion [144]. This was done in both an intermediary and final step of the writing process. Another concept is triangulation where multiple sources are used to cross-check findings [144], which in this work was done by comparing statements from different interviewees in each category with each other as well as with literature.

3.2.2 Ethical issues

Concerning ethical issues, four aspects used to avoid transgression of ethical principles in research are harm to participants, lack of informed consent, invasion of privacy and deception [144]. These questions were considered during the entire research process. All interviewees participated voluntarily and were informed on the approach and intentions of the thesis both before and during the interview. The questions posed were formulated in an open and neutral way and the interviews were conducted in Swedish, except when asked for being conducted in English. This ensured the possibility for the interviewees to express themselves freely and more nuanced than if all of them would have been in English. However, some of the follow-up questions were more closed-ended with the purpose of either assuring that we understood the interviewees correctly or changing the direction of the interview.

The choice of including a list of the interviewees with a description of their role was made since this validates their competence in the field and motivates the ability of us drawing conclusions from their answers. This was made in consent with the interviewees and their descriptions were either provided or approved by them. Anonymity and confidentiality still being important, the analysis was made without linking specific interviewees to any statement to minimise the possibility of identification why “they” is used also as a gender-neutral singular pronoun. Conforming to respondent validation [144], all the interviewees were given the chance of proofreading and giving feedback on how we have handled their responses the report both at a draft stage in June and towards the end of the thesis work in August. With this in mind, the risks from the four aspects are considered to be minimized to the best of our ability.

Another aspect discussed during the process was the demography of the interviewees. The focus has been on finding relevant persons rather than getting a heterogeneous mix of people. As a result, most of the participants are middle-aged men and only five are women. However, this is not judged to be an issue in the reliability of the data obtained since the important demographic here is the field the interviewee is in. Thus, the aim has been to have an equal mix of actors from the different categories and therefore the role is what has been sought for.

4 Results

The results of this thesis diverge into three sections. The first and most extensive section treats all three research questions and presents the interview findings categorised into five divisions; policy instruments, fossil free transition, energy systems, bioenergy and CCS. The second section focuses on the first research question via a policy landscape overviewing the Swedish and EU policy instrument currently on the horizon along with comments and forecasts on their future. Lastly, the third section treats bioenergy feedstock options and comments on the potentials and predictions of each, thus treating the third research question.

4.1 Interview findings

In this first result section, the responses from the 25 interviews are presented under different subdivisions including the interviewees' opinions, agreements and differing views. Recall the categorisation of interviewees into energy actors, bioenergy providers, academics and environmental actors presented in Section 3.1.2. Note that there are mentions of the consequences of and parallels to the COVID-19 pandemic[1] spread over the following sections since there was inevitably a high prevalence of COVID-19 during the time of interviewing and writing. In Section 4.1.2, there is also a separate subsection on the matter.

4.1.1 Policy instruments

To transition to a fossil free society using bioenergy, all interviewees agree policy instruments play a key role while noting that they can both help or harm depending on formulation, execution and implementation. This section presents opinions on existing policy instruments, tendencies and desires for future policy instruments as well as identified political challenges and desired requirements from policy-makers. Policy instruments specific for certain topics are not treated here but instead lifted in their respective sections, which regards policy instruments concerning the energy system, bioenergy production and the forestry sector as well as the transport sector and the recently implemented tax on waste incineration.

Opinions on existing policy instruments

Starting with existing policy instruments, one of the academics notes the current ones are not optimal but convey it is not an easy task. As for Swedish policy instruments, some actors lift the positive impacts generated by the CO_2 tax and its importance in turning the energy sector almost fossil free already. A few actors raise the Reduction obligation as working well. Two academics believe it will remain and expand to include more sectors, where one even states it could become the most important environmental policy instrument in Sweden along with the CO_2 tax. An environmental actor remarks that the Swedish climate law enforces climate consideration in all political areas but notes that not all ministries seem to take this seriously. They speculate if moving the responsibility to the Ministry of Finance or the Prime Ministers Secretariat would give the issue more ponderosity[2]. One energy actor implies the directives enforced last year of taxing fossil fuels in heat and energy production are intricate

[1] The novel coronavirus disease (COVID-19) was first discovered in the Chinese region of Wuhan in December 2019 [148] and was characterised by WHO as a pandemic in March 2020 [149].

[2] Given the brand-new Klimatkollegiet (June 9th), things seem to be moving in this direction already about a month after the interview occasion. The Klimatkollegiet will be part of the Prime Ministers Secretariat and aims to interlace climate issues into all relevant political areas [150].

and negatively impact bio-oils as well due to the EU State Aid rules on overcompensation[3]. Another energy actor remarks that regulations creep closer onto bioenergy, endangering the development of bioenergy use due to harsh, peculiar regulations. They further note fossil industries profit off of this and mention that the fossil industry lobbyists influence the regulations. Moving to charges, one actor implies that they are juridically difficult but notes that the current NO_x charge works well while another actor dislikes the entire concept of charges, including the NO_x charge.

Turning to existing policy instruments within the EU, the most prominent ones are the ETS and the State Aids. Two actors highlight the positive impacts generated by the ETS, where one of them, an environmental actor, emphasises the importance of high carbon costs as they strongly believe polluting should be costly. However, this actor notes there are still several gaps in the ETS system and exemplifies with long range flights, as their emissions are not allocated to any country. On the other hand, a bioenergy provider expresses concern over ETS allowances becoming too expensive, which they mean will negatively impact the entire energy and heat sector, especially waste incineration as this has a relatively large share of fossil emissions. Another actor agrees ETS complicates the energy sector, meaning that with the Swedish system, where all boilers over a certain size in a system are included in the ETS, this hinders utilisation of waste heat from sources not previously included in the ETS. As for the future of ETS, two academics mark that the allocation is changing towards auctioning, which one of them states is desirable since this makes it more like a CO_2 tax. This actor notes that free allocation was very important when starting ETS as this helped get unwilling, large companies and industries on board. A bioenergy provider believes ETS will be expanded to include the transport sector, buildings and the agricultural sector, which they mean will open up for more policy instruments. Moving on to the State Aid rules, the overcompensation issue lifted above trouble multiple actors. They convey the Swedish strategy to increase biofuel use by subsidisation has been blocked by the State Aid rules, meaning biofuels will become substantially more expensive. One bioenergy provider states that the implemented Reduction obligation arisen from this stops further development of biofuels. An energy actor notes the State Aids regulate everything and generates inertia. Further, they mean it becomes difficult and unpredictable when all nations' different needs have to be squeezed into the same regulatory framework.

Other European instruments mentioned are the upcoming implementation of RED II and the Green Deal. One actor working up-close with politicians considers RED II to be the most discussed legislation at the time with the government working on laws and directives to implement it. Several other actors express that the implementation of RED II sends an important signal of the future of bioenergy. A few express risks of RED II limiting what can be classified as sustainable biomass, mainly due to strong forces in Europe against biomass use, while another actor marks the different member states' ways of setting their goals as the most ponderous. Two actors see that the implementation of RED II into Swedish legislation will cause more administrative work, but are both hopeful that the implementation will turn out quite well. As for the Green Deal, there is mainly one bioenergy provider who elaborates on the topic. This actor is hopeful the systematic classification for the financial sector proposed by the Green Deal will help redirect money into green investments while simultaneously expressing criticism of the system. They point to tendencies within the EU to categorise things that are considered sustainable in Sweden as unsustainable as well as over-generalising between European countries which the actor means is impossible due to their different circumstances and conditions. This problematic connects to similar opinions among other interviewees on the EU's view on sustainable biomass, which is further treated in Section 4.1.4. Additionally, the same bioenergy actor believes the Green Deal will increase the value of biological material, even for energy purposes. However, they believe the

[3]For EU State Aid rules see Section 2.4.2.

implementation of the Green Deal will be challenging, as there is a need to get heavily fossil-reliant nations on board. A couple of other actors simply note the Green Deal as unpredictable.

Lastly, concerning Swedish and EU policy instruments, one environmental actor states the Swedish legislation is sometimes stricter than the EU's as the EU needs to accommodate to all members and adapt to those with the hardest time to meet the requirements, whereas a bioenergy provider conveys the EU legislation is stricter as regulations on the EU level causes fewer trade barriers than if Sweden were to implement them alone.

Future tendencies and desired policy instruments

For future tendencies of policy instruments and what the interviewees deem would be needed to make the transition to fossil freeness, the most prominent opinion concerns the polluter pays principle in one way or another, but also other kinds of policy instruments are suggested. An environmental actor underlines the need of policy instruments to adhere to other environmental aspects in order not to undermine the sustainability of climate interventions. Another environmental actor conveys that a functioning policy instrument combines three aspects: efficient targeting of the desired outcome, cost-efficiency and societal acceptance of the implementation.

Many actors agree it should be costly to pollute and that the polluter should pay. How the different actors interpret the concept of the polluter paying however varies. Where most seem to consider only GHG emissions, one environmental actor considers the concept to also apply to it being costly to pollute and degrade ecosystems during land use when recruiting biomass. Multiple actors suggest a CO_2 tax as a way of achieving the polluter pays principle, where one puts it as simply keeping track of what needs to disappear, there is no need to over-complicate things. Another actor notes that taxes work well on the consumer side but implies that it is more difficult to achieve the desired effect on the industry side. They deem taxes as a quite blunt policy instrument, used for fiscal reasons rather than actual governing. Some actors advocate the producers should be held accountable for what they put on the market and imply that the polluter cost should be paid by those using fossil resources. One justifies this by elaborating that the lion share of the economic gain in the value chain occurs at the producer level. In addition, a few actors promote rewarding carbon neutral sources, such as bioenergy and other biomass-derived products, while making it more expensive to use fossil energy sources. One of them means the largest impact would be achieved if targeting the big polluters and helping them make greener decisions by government regulations. An environmental actor indicates that environmental damage needs to be internalised into the cost of goods, as they believe this would help to change peoples' behaviours and consumption patterns. The same actor proposes over-flying could be eradicated if implementing an exponential tax on plane tickets, meaning one ticket would cost "normal price" but buying again would double the tax each time. They mean this would effectively end business-flying and other over-flying, while still being quite equitable for people who need to take a flight once in a while, as they see the frequent-flyers are the main problem.

Several actors emphasise that it has to be costly to pollute everywhere, in the entire world. Of these, two promote a high CO_2 tax, one states simply a high carbon price while another one cares about which instrument is implemented as long as it is a mutual one. In fact, two actors mention there is already dialogue in the EU of implementing a common CO_2 tax as a complement to the ETS. One of them states it would be much lower than the Swedish one but means it is still a step in the right direction. Another actor speculates if an international supervising body would be beneficial but sees that there would be issues with debates on it being dictatorial and on the freedom of speech. Another interviewee emphasises there cannot be a supranational union collecting tax and underlines taxes should be handled nationally so that each country can decide where to put the money to best use for their specific case. Yet another actor is on the same track, implying it is not desirable to have a supranational issue locking up money for certain uses as they believe it is problematic in a societal perspective and against the principles of taxes. This actor sees the youth environmental movement as wanting to prioritise climate issues into supranationalism and draws parallels to the large expenses occurring now due to COVID-19 and points to the problematic of having money locked for climate issues at times where it is desperately needed elsewhere.

Leaving the policy instruments dominated by the polluter pays principle, one actor states CO_2 taxes are great and all, but sees that the distributional and competitive effects are toilsome before new technical solutions arise. In certain cases, this actor means it is quicker and cheaper to implement bans on bad goods to force a fast technical development instead of putting a tax since they claim bans create a more secure market for investments. A couple of other actors agree bans are sometimes needed; one believes there might sprout more bans similar to the one on plastic straws on South European beaches[4] and another notes that bans are becoming more acceptable making it possible to include GHG into the future Swedish environmental permits. Continuing on market aspects, several actors promote general, technically neutral policy instruments. They convey this would allow for a competitive market that can decide which options provide the most cost-effective solutions. Three bioenergy providers imply this would be desirable for the development of bioenergy; two since this allows for investments in the most high-grade, profitable products which they mean inevitably generate residues that can be elsewhere utilised, and the third since they believe bioenergy is better suited for industrial processes than electrification. Moreover, two actors see an upcoming trend of quotas in Europe, similar to the Reduction obligation, and imply this could be a good way of substituting fossil market shares with renewable energy sources and green technologies. One of them elaborates that quota systems create stable market conditions that diminish investment risks of new green technology or production plants.

Multiple actors express a desire for soft policy instruments either to target consumption patterns and make people aware of and take responsibility for the impacts of their choices or to facilitate communication, collaboration and experience exchange between actors. One bioenergy provider implies these soft values are often underestimated but convey that people choose certain options based on them “feeling good” even if it might be more expensive and exemplifies with farmers choosing to drive on biofuels regardless of it being more expensive than fossil alternatives. Lastly, an academic believes there will be many diverse temporary policy instruments facilitating the transitioning that will later be phased out, such as investment aids and support for developing new technology, and an energy actor accentuates there need to be policy instruments ensuring the expanding rate remains sustainable.

Challenges related to policy instruments

Most interviewees see political and policy instrument related challenges in the transition to a fossil free society. The most prominent issues concern unpredictable politics and decisions that risk failure along with challenges within the political situation. Other challenges include other nations having different conditions, market aspects of investment and fossil subsidies.

The concept of uncertain politics is the most frequent answer to what the interviewees think is hard to predict, raised by half of the interviewees. By extension, politicians’ views on sustainable biomass

[4] In March 2019, the EU Parliament voted on banning plastic straws and other single-use plastics which will enter into force in 2021 [151]. In some locations, banning has already started, e.g. Spain, Italy and England [152, 153, 154].

and bioenergy as well as unpredictability in political decisions are often mentioned. Some actors convey political decisions are often arbitrary and not always well thought-out, and imply this harms the potential development of green technology and biomass production as it gives an unstable, risky market. Several actors remark that policy instruments to date have never been sufficiently long-term, thus creating a riskful market environment where investors do not dare to gamble on their profitability in case new, contradictory regulations would arise. One elaborates by stating that the EU has had an average period of only 6-7 months without alterations to the regulations during the past 10 years. This actor continues that the lack of long-term perspective leads politicians to make short-term decisions that generate fast results in order to re-win the next election, but problematises how these short-term changes rarely never impact the bigger picture nor sufficiently contribute to combating climate change. Other actors express concern over how the constantly changing political view on sustainable biomass affects the development of bioenergy and other biomass-derived products. One energy actor specifies that there are so many potential good solutions that there are no safe bets, and that what will be most beneficial highly depends on these uncertain political conditions.

Some actors highlight how increasing political polarisation negatively impacts the probability of politicians reaching agreements. One academic conveys that the polarisation makes politicians target niche questions instead of aiming for major overall issues, such as combating climate change. On the same note, another academic remarks that politicians avoid making big decisions and instead create a patchwork of several, small decisions. A couple of actors observe that the political process is slow, delaying implementations of policy instruments or conditions needed for bioenergy to enable fossil free transitioning. One expresses the need for more action and concrete decisions, while another conveys that the slowness is necessary to ensure democratic procedures, for better or for worse.

Several actors also lift politicians in themselves as a challenge, partly since they deem that politics is based on opinions and values rather than actual science and facts, and partly since they perceive that politicians neither understand nor accomplish enough. For the first part, multiple actors express concern over what impacts will be caused by decisions that are not sufficiently based on broad, scientific foundations without a holistic perspective. One actor underlines that more decisions need input from expert councils and draws parallels to how the Swedish Government heavily relies on the Public Health Agency now in times of COVID-19. They believe more decisions should be discussed with people who are educated on the specific matters. Another actor sees that the scientific foundation has increased over the past years and that more investigations are made today. However, they note these investigations leave more to be desired as the impact analyses are often narrow and shallow. A couple of actors remark that the reason decisions are made the way they are is because politicians follow shifting opinions and trends. One elaborates that politicians only want to win votes and conveys that they do not dare to tell the truth, because no one wants to hear the truth, thus implying people want politicians to say everything will be alright. An academic adds to the same note that politicians keep adjusting policy instruments to please loud protesters who are dissatisfied with a regulation, even if the whole point was for them to be affected by the regulation. For the latter part, and building on the scientific foundations, some actors imply politicians would need more education to fully understand the gravity of climate change in order to take it more seriously. A couple of actors remark not enough has been done to combat climate change and that it takes more effort.

An issue lifted by several actors from all actor groups is other nations having other conditions and prerequisites, leading them to interpret concepts such as “sustainable biomass” very different from how Sweden does. This creates friction when negotiating policy instruments to agree on, both between politicians from different countries and also between environmental organisations, politicians and implementing authorities. Within the EU, multiple actors see a dispersion of policy instruments as each member state interprets the common directives somewhat differently depending on their own specific conditions. A common competitive market added to this makes some products more profitable in other countries as they can play on benefits from both production and use, some actors note. Thus, creating policy instruments that will work everywhere is dismissed by several interviewees as not achievable. One energy actor implies that the complexity within the directives giving different interpretations on implementations is partly intentional since it can be favourable to have varying degrees of strictness in different countries. One academic believes the insight and understanding of different nations having different conditions and prerequisites facilitates the transitioning to a fossil free society, sprinkled with several diverse custom solutions.

A more concrete challenge is the need for large investments, especially in bioenergy development, an issue raised by many as they see the uncertain political situation hindering this. Without stable conditions, no one dares to invest in new technologies and developments as there is no guarantee of return of investments, nor of profitability. Some actors highlight that this makes it difficult to scale up demonstration plants to commercial scale and express a desire for policy instruments facilitating this up-scaling. An academic specifies that no investor makes an investment with a longer pay-back-time than what they can foresee given current policy instruments and market aspects, which they mean is maximum five years implying large investment are impossible in a market economy without policy support. Additionally, a bioenergy provider remarks that no one will invest in something that will not be competitive in the long run regardless of potential support. This need for large investments leads to the notions of money driving the transition and future consumer behaviour, concepts that are further treated in Section 4.1.2.

Another significant challenge for achieving a fossil free society, lifted by three actors, is that there are a lot of subsidies on fossil fuels, which they all agree needs to be eliminated. Together with multiple other actors, they see strong economic interests from the fossil lobby obstructing the abolishment. Two of them note politicians are afraid of implementing CO_2 taxes due to harsh opposition and protests from civilians. A couple of actors remark it is hard for bioenergy to compete with oil when it is as cheap as it currently is and that the fossil lobbyists do their best to keep it that way.

Desired requirements from policy-makers

Building on the desired policy instruments and identified challenges, the interviewees express desired requirements from policy-makers along with what they believe is needed to make the transition to fossil freeness; topics most of the interviewees agree on. A positive thing lifted by multiple actors is that there is a political will to guide society forwards. One academic states policy instruments as the last piece of the fossil freeness puzzle, claiming Sweden already has the rest laid out; substantial biomass resources, functioning industry and energy infrastructure as well as extensive technical knowledge and research.

There is consensus among the interviewees that clarity, distinctions and long-term perspectives are required in policy instruments, whether to transition to fossil freeness or to advance bioenergy systems. Some actors add mutual overall responsibility, stable conditions and broad agreements to the requirements, especially to advance bioenergy systems. Other actors express that politicians have to be braver, stand up for and stick to decisions enabling climate combating, and not make alterations as soon as someone utters discontent. The same kind of strong, collected leadership seen now in times of COVID-19 would be beneficial also for combating climate change, as expressed by a few actors. One environmental actor conveys that Sweden has had a quite neoliberal political perspective with a belief of every little individual contribution being enough, but means that we have now come to a point where it is not. They see it is time to start governing in the issue of climate change as the concept and interpretation of sustainability is highly dependant on the beholder and their values.

Moreover, most actors see that implementing clear, distinctive policy instruments considering the long-term perspective would help minimise the risk of large investments, which would enable more investments and development in bioenergy and commercial-scale production plants as it removes the profitability uncertainty. One actor notes that market stipulations are needed to interconnect actors and create stability. They convey lone industry actors will be more prone to change if they know other industry actors promise to change too. Elaborate political conditions are required to achieve this, according to this actor. Another actor remarks that decisions and changes need to be anchored between all affected parties during the development phase of policy instruments in order to create involvement and willingness to implement the decisions once they are made.

Another requirement, lifted by almost half of the interviewees whereof no environmental actors, is for politicians to protect and advance Swedish interests within the EU. However, most of these responses specifically concern Swedish forest management and views on sustainable biomass production, why this is further treated in Section 4.1.4. By contrast, two energy actors lift energy systems and tax directives where they see a need to fight for the Swedish perspective in the EU, connecting to the overcompensation of bio-oils mentioned under opinions of existing policy instruments. To conclude, one energy actor states there are two sensitive fields that need to be traversed to create functioning policy instruments: the distribution effect and competitiveness. To achieve this, skilled leadership with acceptable distribution politics is required, according to this actor.

4.1.2 Fossil free transition

There is consensus among the interviewees that the fossil free transition is crucial to reach the climate goals and they identify both possibilities and challenges on the way. One interviewee expresses the fossil transition as the only possibility since the other option is unthinkable with continuous destruction of the planet. However, there are obstacles on the way which are presented in this section along with possibilities, necessities, market and social aspects as well as the future role of Sweden and parallels to the COVID-19 pandemic. Lastly, some opinions on greenwashing and carbon offsetting are expressed.

Possibilities with the fossil free transition

Starting on a positive note, there are multiple factors that the interviewees identify as key facilitators in the journey of becoming fossil free. Several interviewees state that there is widespread awareness of the climate question and that there is a willingness to change, but note that the average person does not know what this change will look like. A couple of actors highlight that it is possible to combine the transition from fossil-based materials with increasing welfare and standard of living and that this aspect is something that Sweden can show other countries and encourage them to follow. They further declare that the required technology development will not be an issue while another interviewee expresses the need to make use of existing investments and systems to obtain a faster transition. This calls for bioenergy feedstock options that can quickly replace fossil fuels but one academic accentuates that the well-established systems can also slow down the transition. Furthermore, two of the environmental actors state that even though technology is necessary and will be developed, it can be dangerous to rely too much on technology that is yet to come since that can lead to pushing problems ahead of oneself instead of making an effort right now.

The speed of the transition being uncertain, some interviewees still believe it will be fast. Two others express that the development will come with trial and error, implying that progress is achieved step-wise with the notion of two steps forward, one step back. One of them highlights that this slow pace is necessary in the democratic world we live in, where the opinion of many is preferred above one almighty ruler that decides on what development to choose. Regardless of the error-induced step back, one interviewee emphasises that the step back should never exceed the advancements, resulting in a continuous progress towards a carbon neutral future. The step-backs could however act discouraging on people's willingness to change, according to one bioenergy provider. They emphasise that people tend to remember when things went wrong which makes them reluctant to jump on board next time.

In the suite of the COVID-19 pandemic, several state that national supply chains are essential since they are less vulnerable in case of a crisis. This desire for self-sufficiency encourages local alternatives which in the case of Sweden implies that fossil fuels are losing ground, leaving place for renewable sources. One bioenergy provider promotes focusing on building a green society in addition to emphasising the removal of emissions from the economy, which can help to gain confidence from the citizens. However, another bioenergy provider emphasises that certain additives and chemicals are, and will continue to be, imported and that 80% of the forest products being exported, why self-sufficiency is not fully reachable, even though most of the raw materials can be supplied nationally. In the case where some imported good is missing, this could lead to discontinued production and thus decrease the availability of byproducts for energy purposes.

Challenges with the fossil free transition

The fossil free transition does not come easy and the interviewees express different aspects hindering the transition. One of the big ones is the current reliance on fossil fuels with all the investments made, providing the world with cheap energy creating a threshold effect preventing the transition, according to one bioenergy provider. One environmental actor adds that the existing fossil systems encourage further exploitation of oil and its properties instead of developing green options. Some of the interviewees point out the great financial and lobbying power of the fossil industry and how they will fight for their own survival. One of the environmental actors exemplifies with how the fossil industry wine and dine policy-makers during climate negotiations to promote their own agenda on sticking to fossil resources. The same actor also emboldens society to dare stranded assets[5] of the fossil investments made, irrespective of reaching the return of investment.

As mentioned, policy instruments need to be global, and so does the fossil free transition. However, some bioenergy providers express uncertainty regarding this global transition. Everyone needs to contribute but in the end, it comes down to money. When a country relies on cheap fossil energy, the transition might result in huge economic impacts. Poland is an example used by two bioenergy providers, where they doubt Poland's willingness and economic capacity to phase out their coal power. One interviewee lifts the need for technical development to make the transition efficient and profitable and another expresses the fear of a societal collapse following the transition and draws parallels to the COVID-19 crisis. The economic aspects are raised by a couple of actors. One energy actor states that it is hard to go all the way fossil free since the profitability will decline and the last percentages will be extremely expensive to replace. There is also the question of whether or not the change you make will be profitable, entailing that everyone waits for others to take the first step, according to one bioenergy provider. Nevertheless, one interviewee states the need for funding to retrofit the economy and keep

[5] Stranded assets are defined by the Smith School of Enterprise and the Environment as "assets that have suffered from unanticipated or premature write-downs, devaluations or conversion to liabilities" [155].

building for a more sustainable future.

Further, a few interviewees acknowledge that not enough is done to combat the climate crisis. One of them refers to Sweden being on 4^{th} place in the world on reaching the commitments made in the Paris Agreement but no one is on place 1 to 3[6]. Another has accepted the idea that we are past the point of no return and that the mindset needs to change from recreating the nature that was to sustainably developing and making the change less abrupt. One environmental actor is less positive and declares that we are too far down the line and that circular economy and a sustainable future are not enough but regenerative alternatives are required. They further declare that the biosphere does not care about the extra effort the single person puts in and that we are too quick in congratulating ourselves for contributing to climate change mitigation that we risk not doing enough.

Market aspects

Several interviewees, most of them bioenergy providers, stress the importance of maintaining Sweden's competitiveness in the transition and promoting business solutions that make everyone participate on equal terms. High sustainability requirements on the Swedish industry might result in increased prices that are not competitive in an open economy if others have less strict requirements. As one academic says, being part of the EU makes it difficult to limit import from other EU countries. Support is necessary in the beginning, but as previously mentioned, many actors note that regardless of potential support, no one will invest in something that will not be competitive in the long run. Competitiveness is not just an issue between Sweden and other EU countries, one energy actor mentions the threat Asia poses on the global market due to their rapid technical development and digitalisation. They point out that the EU can keep its competitiveness by being leading in climate actions. An aspect, as expressed by another energy actor, is that trade streams are uncertain and can change if for example, one country decides to make use of national resources instead of exporting them. One academic adds that competition can lead to saturation of the market share which reduces the price, whereas the market uncertainty nowadays is greater than the uncertainty of policy instruments.

Building on the uncertain market for large investments mentioned in Section 4.1.1, many interviewees from all actor groups share the opinion that money drives the transition and that companies get on board voluntarily in order to increase their own profitability, at least in Sweden. This is indicated by companies' sustainability reports and creates pressure on the politicians. One bioenergy provider points out that a general policy instrument on CO_2 is required to ensure equal competition, which enables the market to do its job on technical development. Another bioenergy provider states that profitability is key in obtaining social and ecological sustainability. Some actors express that money can also stand in the way, as in situations were a company chooses profit over climate benefits. The optimal is when one does not exclude the other, but a couple of actors remark that companies always do what is most profitable for them and promote their own agenda. In a market-driven system, the consumer is king and a few interviewees bring up the uncertainty that follows with future consumer behaviour. One highlights that the younger generation is more aware and lifts vegetarianism, veganism and reuse as examples. Another expresses incertitude in how circular the economy will become and a third worries that consumers do what they believe is good and beneficial but that this can be sub-optimal in a greater perspective. A last thought is from a bioenergy provider that suggests the importance of social acceptance from consumers in order for necessary changes to happen.

[6]According to the Climate Change Performance Index 2020, no country performs well enough to be ranked in the top three places. Sweden performs best and has done so the last two years [156].

Necessities for the fossil free transition

The interviewees have identified certain aspects necessary for the fossil transition. To begin with, many interviewees, mainly bioenergy providers and environmental actors, express a need for changed behaviours in society while noting this change does not come easy. The main area is consumption, where they lift both the need for reduced consumption and that consumers should make active choices to promote sustainable options, of both energy, goods and services. As one environmental actor states, "The energy you don't have to supply has no impact on the climate". One interviewee reminds that Swedes live as if we had more than 3.5 Earths[7]. Almost all environmental actors describe flying as a big issue and want people to reduce their flying. One of them points out that it is possible to maintain your quality of life and preserve the climate at the same time, and that life quality is not defined by how often you fly to Thailand. One energy actor accentuates that it is difficult to live a fossil free life in a fossil dependent world but that once the transition is made, it will be easier for the average person.

Another aspect agreed on by many, is the need for public participation by information and education regarding climate issues. People will not change unless they understand why since sticking to habits requires less effort. A couple of actors believe that people are afraid the transition will demand sacrifices, why it is of great importance to explain how the transition can be beneficial and thus create a willingness to change and a greater acceptance in society. One of them voices the possibility of a future that is not as we imagined but at least good enough. They further note that it is difficult to get the individual's wishes to rhyme with what is best for everyone since this implies that some need to renounce from certain wishes. Another interviewee elaborates that in our age of social media it is easy to be heard but harder to evaluate the correctness of a statement, and one environmental actor adds that some people are not willing to change their strong opinions, regardless of scientific evidence in other directions. One bioenergy provider stresses that even correct information can be distorted depending on how it is presented, for example by only showing mean values which can seem reasonable but simultaneously hide peaks and troughs that tell a completely different story.

It is also of great importance to have a holistic approach to the fossil free transition, which is acknowledged by a lot of interviewees. There is no single solution but a balance of taking in aspects from all areas. One energy actor illustrates this by comparing it to whac-a-mole, when you make a change somewhere you will get aftereffects elsewhere in the chain but it is hard to predict where it will strike. The choice of boundary limits affects the outcome, which half of the environmental actors express regarding emissions. They stress the need for including emissions from import to the territorial emissions[8] to identify each nation's contribution to global emissions.

Finally, many actors express the need for collaboration between politicians, companies and other actors to achieve the transition. Decisions need to be anchored and based on an understanding of the system. One environmental actor emphasises the need for a continuous dialogue both during and after the transition to ensure societal and ecological sustainability. Some actors raise the conflict between the forest industry and environmental organisations on the balance between production and biodiversity that has been going on for a while, where each part has their own view and neither agrees with the other, which is further elaborated in Section 4.1.4. Getting actors to collaborate is however

[7] According to WWF's Living Planet Report 2018, in Sweden, we live as if we had around 4 Earths [157].

[8] The Swedish Environmental Protection Agency states three ways of accounting GHG emissions: 1) territorial emissions based on activities in Sweden and ground for monitoring climate goals, 2) production-based emissions based on Swedish activities in and outside of Sweden, and 3) consumption-based emissions that include production of the goods we import in other countries [158].

hard, why one bioenergy provider states that a small climate catastrophe would be beneficial since it would force everyone to come together, as is happening now in the suites of the COVID-19 pandemic.

Future role of Sweden from an international perspective

There is a broad consensus that Sweden could act as a role model in the fossil free transition from an international perspective. Though many state that Sweden is a small country emission-wise[9], they accentuate that we can export new technology, innovations and knowledge as well as the capability of staying competitive even after the green transition. Several interviewees underline that the Swedish model can not be copied straight off but everyone needs to adapt the transition to their local conditions. Despite being a small country, a few think that Sweden can be a big influencer in negotiations and make sure that climate is kept on the agenda, in order to get others on board. In addition to this, some see that Sweden already pushes the EU on climate topics and one academic notes that depending on how these agreements hold over time, the credibility for getting the rest of the world to follow increases. They continue that nobody will want to invest in large scale production of some new technology if there is no demand in the rest of the world. One bioenergy provider emphasises that it is also important to be a role model in economic and social sustainability as well, not just environmental solutions, as potential followers might be discouraged by the effort needed if they do not see benefits from the change.

Societal aspects

As stated earlier, society plays an important part in the fossil free transition, however, it is not always uncomplicated to get people to change voluntarily. A couple of interviewees express that people are afraid of change why the transition itself is the biggest challenge. One academic elaborates by illustrating that society consists of three fractions, one part that believes Sweden is too small to make any difference why no change here is necessary, another that wants decentralised, perfect solutions and a last part that wants centralised, large scale solutions that deal with climate change in a broader perspective. They express that most often, the two first parts are the ones that are heard and they can affect the neutral majority. Several interviewees state that despite the widespread awareness and increased interest in environmental issues, many people do not have a strong opinion, due to lack of either interest or knowledge. However, two interviewees point out that some people and sectors want more of everything, including a better climate, which results in a situation of wanting to both have the cake and eat it. One of them adds that a minority feels threatened by the change required since it might be limiting their own development potential and that it can be canalised in loud discontent when trying to fight for their privilege. Furthermore, there are some hypocrites that say they feel strongly about the climate but who do not walk their talk and continue to live their fossil lives, according to two environmental actors. The last aspect, as elaborated by one bioenergy provider, is that people tend to not grasp long-term changes and effects and instead have a too narrow perspective, seeing only what is beneficial in the short term.

Uncertainties concerning the fossil free transition

There is consensus that the fossil free transition entails a number of uncertainties and several interviewees express that nobody knows what will happen in the future. A couple of actors highlight complexity as one important aspect, both coupled to energy provision and global politics. Everything is connected and one bioenergy provider compares it to the cockpit of an airplane with all its interconnected buttons that are all necessary to fly the plane. They continue by encouraging to not be scared

[9] Sweden stands for 0.13% of both the global CO_2 emissions [159] and the population [160].

by the complexity but to dare trying new ideas.

As previously mentioned, people are of great relevance and multiple actors find it difficult to predict the opinion and attitude of the many which notably affects the political landscape in the world. A bioenergy provider adds that environmental organisations pose a bigger uncertainty to bioenergy than society, as they claim the “irrational behaviour of the so-called environmental NGO’s[10] has done tremendous harm in the last decade”.

Several interviewees express predictions of technical development as other hardships since history has shown that technical breakthroughs can come unpredictably. Another unpredictable aspect is unattended events, like catastrophes or pandemics which can have huge impacts. The case of COVID-19 and its impact will be discussed in the following section.

Consequences of and parallels to the COVID-19 pandemic

Many interviewees raised the COVID-19 pandemic in some way during the interviews and though it is mentioned in connection to other sections, two specific areas were identified as deserving elaboration, the consequences following the pandemic and what the recovery will look like.

Starting with the consequences, an immediate one underlined by a couple of actors is that the pandemic makes everything run low, due to efforts and restrictions to reduce infection. This has substantial effects, and one bioenergy provider refers to the International Energy Agency that has observed reduced emissions during the first quarter of 2020[11], and states that this reduction needs to be both continued and increased in the coming years to reach the climate goals[12]. However, the total lockdown of society has proven not to be optimal whereas future reductions need to come from other solutions than staying home all the time. Some interviewees express that the restrictions have required changes in behaviours during the crisis, such as less traveling and increased remote meetings, whereof some might remain even when the acute phase of the pandemic ebbs out. Some worry that the pandemic will exclude climate issues from the political agenda, disfavoured by welfare and healthcare. Two bioenergy providers lift the EU Green Deal as an example since it has an ambitious plan, but question how much will actually be prioritised given the current situation and what money will be available for the transition. A risk expressed by one environmental actor is that each country turns introvert and does not act in line with what is needed internationally. However, one of the other environmental actors hopes that the pandemic will entail increased reliance on experts in order for policy-makers to make well-grounded decisions.

Turning to the recovery, many interviewees speculate in its path post-COVID-19 and see it as an opportunity to rebuild society and enhance the green transition, but also as a threat if another direction is chosen and the fossil industry is granted privileges. However, they all acknowledge the large degree of uncertainty connected to the recovery and to what extent things will go back to how it was before the crisis. Several actors express that governments play a central role in which companies they support, if they support big fossil industries or if they invest in green technology, and one of the actors articulate the opportunity for the governments to claim environmental action in return

[10] NGO is an abbreviation for non-governmental organisation which is defined by Oxford Lexico as “a nonprofit organization that operates independently of any government, typically one whose purpose is to address a social or political issue” [161].

[11] In the Global Energy Review 2020, IEA states a 5% reduction in CO_2 emissions in Q1 and predicts an 8% reduction in 2020 compared to 2019 [162].

[12] IPCC declares that a reduction of 45% of CO_2 is needed by 2030 [2].

from the industries. One environmental actor raise that Swedish politicians declare a need for a green recovery[13]and one bioenergy provider adds that this can promote domestic bioenergy.

Greenwashing and carbon offsetting

The aspects of greenwashing and carbon offsetting were raised by several interviewees, mostly environmental actors. A couple of interviewees express that it is dangerous when companies promote a small green part of their operation when the main activity causes large emissions. Some companies buy offsets to compensate for their residual emissions which a few interviewees fear might create an illusion of doing enough instead of trying to further reduce their emissions. One environmental actor compares carbon offsetting with paying a thin person to diet for you, and state that offsetting endorses the consuming behaviour, allowing people to keep doing it. A couple actors question the effect of carbon offsetting, especially regarding projects in other countries. They underline the need for a verification system to avoid money being paid for something that does not have a positive effect. One of them lifts tree planting as an example, where there have been cases where newly planted trees have burned down or else way disappeared, resulting in no effect. Together with other poor examples, it can undermine the credibility of carbon offsetting, thus further promoting the need for verification.

4.1.3 Energy systems, district heating and combined heat and power

During the interviews, the question of energy systems was lifted in relation to the existing Swedish energy composition along with the roles of CHP plants and DH systems in the future energy system. This section presents opinions on the future energy system along with identified challenges and desired policy instruments. Note that when talking about CHP plants in this section, bioenergy is always considered as the fuel source. Here, bioenergy is broadly used and includes waste, as stated in Section 2.1.1.

The future energy system

When asked about the composition of the future energy system, many actors believed CHP plants and DH systems will be an important part of the mix, particularly in Sweden. Assets lifted include CHP and DH having existing well-developed infrastructure and being able to generate either heat or electricity depending on demand and price, thus acting as an important, stabilising baseload in an energy mix with variable contributions of wind and solar power. A bioenergy provider adds that CHP and DH could be expanded in more countries to become an important component to increase energy efficiency and reduce local emissions. Even with increasing installed capacity of wind and solar, a couple of actors argue wind and solar power is not yet mature to fill the entire energy demand, why current CHP plants will at least live out their lifetime. In addition, several actors points to further advantages of bioenergy-fueled CHP. One of the energy actors accentuates the ability of CHP to produce heat and power where people live, thus shortening the distribution distance. Two actors consider that CHP and DH can play key roles in the fossil free transition, given their possibility to expand energy cogeneration and biorefinery as well as to collaborate with industry. One emphasises both cogeneration and biorefinery entail production of liquid biofuels for transport and industrial purposes in addition to heat and electricity, meaning CHP and DH can play key roles also in the transition of the transport sector. In accordance with a few other actors, they elaborate on the important role of DH to utilise waste heat from process industries and other sources where heat is an inevitable

[13]The Swedish Minister for Environment and Climate and Deputy Prime Minister Isabella Lövin has expressed that the recovery needs to be green and sustainable, and as a step in this direction, the government has prolonged the Fossil Free Sweden initiative until 2024[163].

consequence of production. Moreover, two bioenergy providers highlight the possibility of storing bioenergy without it deteriorating and at an inexpensive cost. Another bioenergy provider points to CHP's ability to handle forest residuals, of which they claim there is an abundant potential. One environmental actor marks the incineration of biomass as more or less the only way to obtain BECCS.

Several actors point out that CHP is not the sole solution for the energy system; it is a complex matrix in need of many diverse solutions, including wind and solar power. One energy actor adds that bioenergy is often left out when talking about renewable energy, hidden behind solar, wind and water and they wish to include wood on the renewable agenda[14]. One of the environmental actors underlines the importance of not relying 100% on only bioenergy, and also to be careful not to market it as a universal solution. They state bioenergy can work well under Swedish conditions but that these conditions are quite unique for Sweden, which several actors mentioned concerning the fossil free transition (see Section 4.1.2) or the future role of bioenergy (see Section 4.1.4).

One component in the future energy system promoted by many is energy-efficient buildings. The common arguments are that energy-efficient buildings reduce the overall energy need and can utilise lower grade heat, meaning the temperature in the DH network can be lowered which in turn means more waste heat can be utilised. One actor remarks the challenge in the reconstruction of houses; the window of opportunity is small as efficiency measures can only be done in combination with other renovations and if they are not done at one renovation there will not be another opportunity until the next renovation. In addition, they note rents cannot be increased indefinitely to accommodate the efficiency measures either. An energy actor is a bit cautious of the trend of building owners wanting their constructions to be entirely electrified and self-sufficient since this actor means the year-round supply of heat and electricity is hard to obtain if decoupled. Another energy actor strengthens this as a trend and notes there is volition in society to phase out CHP due to the opposition of producing electricity by incineration. This volition is shared by one of the environmental actors, who believes there will be less need for CHP in a more efficient, integrated energy system.

Another component is geothermal energy[15], which is described by a few as a possible game-changer for the energy market and especially the DH system. These actors agree geothermal energy will not be the only solution but are hopeful that it will play an important role. Also, seasonal storage is promoted by a few, where one elaborates it should be developed further so that more excess electricity could be utilised as heat. On a more local level, a couple of actors express hope for Göteborg Energi's GoBiGas project[16] and believe maybe now the time is right since the price of carbon has increased and the push for fossil free energy production is accelerating.

[14] This is a play with words in Swedish, where "Sol, vind och vatten" from the famous song by Ted Gärdestad is suggested to be replaced with "Sol, vind, ved och vatten".

[15] Geothermal energy utilises the Earth's internal heat to generate electricity or produce heating and cooling [164]. Geothermal energy is a reliable, fossil-free source of DH which in Sweden would require a borehole depth of 5-7 km according to the Geological Survey of Sweden [165]. They further note Sweden has untapped potential of geothermal energy, with only Lund having small-scale geothermal energy supplying one-fourth of their DH system since the mid-1980s.

[16] The GoBiGas project was a collaboration between Göteborg Energi and Chalmers University of Technology which included a demonstration and research plant where forest residuals are gasified to biogas. The plant was taken into operation in 2013 and the initial plan was to expand to a full-scale commercial plant in a second stage of the project. Due to profitability issues, this was dismissed in 2015. The GoBiGas plant operated until 2018 when the board of Göteborg Energi decided to discontinue. During its operation, the GoBiGas project has successfully demonstrated that the technique of gasifying forest residuals can be used at commercial scale and with high efficiency [166, 167].

Challenges for expanding the energy and district heating systems

When it comes to challenges for the energy system, those in favour of CHP and central DH systems lift hinders and obstacles for expanding this. The most prominent one is the profitability issue of CHP and DH, which in turn is closely related to both the question of power vs. energy and to a need for policy instruments supporting or rewarding power capacity. Several energy actors see a risk of heat pumps outcompeting DH, either if the price of DH increases or if environmental accounting calculations disfavours DH compared to individual solar cells paired with heat pumps. As previously, the main problem they see with heat pumps is the year-round supply. One actor elaborates and argues that the environmental calculations and guarantees of origin are nothing but a juggle with numbers, allocating renewable energy to accounting books without changing the actual amount of green electricity in the system.

Other challenges for the energy system in general include the location of energy sources, the European market, the competition of biomass resources between different sectors and solar energy. Starting with the location, a couple of actors highlight the need to produce energy and especially heat, where people live at the time it is needed. One notes the bioenergy resource is not located where people live and the other implies it is hard to fill the energy demand on a cloudy, windless winter day if one relies solely on solar cells.

As for the European market, some mention it is still heavily reliant on oil, coal and natural gas for heating and electricity and that most countries lack DH systems. They imply the European transition to fossil freeness will be more complicated compared to the Swedish one, partly as many countries see natural gas as an environmentally friendly option compared to coal and oil, and partly as it is not possible to substitute all fossil sources directly with bioenergy since there will not be enough. For the first part, one of the environmental actors promotes switching the name of natural gas to fossil gas to facilitate people's understanding of its environmental impacts. The latter part leads to the question of how much biomass resource each sector can claim, an uncertainty lifted by several actors, which is further treated in Section 4.1.4. One energy actor points out Sweden's energy connection with German and Polish coal power plants due to financial aspects, the need for base-load and physical proximity. They argue coal will stay on the margin for a long time, even when the average energy mix becomes greener. Another energy actor notes an aversion in European countries towards DH as it is perceived as a forced reliance on large, centralised plants.

The fact that solar power is viewed as an attractive energy source, not least by consumers, makes some actors believe in its development. One actor argues that the learning curve has drastically reduced the price, making solar power much more realistic on a large scale. A couple of actors lift the problematics with storing solar energy between sunny periods, that in Sweden can be longer than expected, and another actor is downright frustrated over the public opinion on solar energy. This actor means consumers believe they are self-sufficient in solar energy since the overall year capacity corresponds to the yearly demand but stresses that what consumers do not understand is that heat demand and solar energy production do not correlate making the system highly reliant on storage or back-up capacity.

Moreover, some uncertainties brought up when discussing other topics tangenting the energy system include the lobbying activity from the fossil industry hindering the development of greener alternatives, the fact that money drives the transition and the difficulties of predicting technical development as well as needs and desires of future consumers, which are all topics already treated regarding the fossil free transition (see Section 4.1.2).

Policy instruments concerning the energy system

As previously mentioned, many interviewees, mainly energy actors, express a need for policy instruments supporting power capacity to keep CHP plants in the system since they see a risk of CHP plants losing their profitability with decreasing electricity prices. The actors agree the back-up power capacity CHP offers needs to be rewarded. One energy actor states that capacity discussions have been held on a political level, but that it is hard to get them to agree. The actor continues that the issue of capacity inevitably leads into discussions on nuclear and hydropower, and whether or not these should be included in a potential capacity support scheme, which the actor conveys is a difficult, divided political issue. Another energy actor suggests introducing a tax on direct electric heating since they argue this is not an efficient use of electricity and that society will need to start economising with electricity. A third energy actor agrees with the latter, emphasising 1 kWh electricity and 1 kWh heat are not the same. They underline the importance of using electricity at high-value usages and for heat demand utilising lower grade heat. However, the same actor claims the current Swedish building regulations distort the potential for DH by steering towards electric heating since this can be beneficial for environmental certification of buildings, which this actor declares results in increased electricity use when the demand is already high[17].

Turning to existing policy instruments, multiple actors mention the historical importance of the electricity certificate system in expanding the renewable share in the current energy system but all agree it has now served its purpose and that its upcoming stop date is timely[18]. A couple of actors mention the so-called white certificates[19] where one dismisses it as too administratively heavy compared to the benefit while the other believes it might be an interesting challenge for the energy producers. For upcoming policy instruments, two energy actors express inquiries over the implementation of EU directives affecting the energy and DH systems. They both highlight the individual measurement of DH which the EU pushed for that Swedish politicians gave in to[20], even though both imply this system is ineffectual since DH is always part of the rent in apartment buildings in Sweden and not something an individual tenant can affect.

4.1.4 Future and development of bioenergy

This section starts off with a broader perspective on possibilities and challenges with bioenergy with a separate paragraph on biodiversity and environmental issues and continues with more detailed issues related to forestry, agriculture and waste.

[17]The building regulations by the Swedish National Board of Housing, Building and Planning (Boverket) do not account electricity produced from solar, wind, land or water at the building site into the buildings energy consumption [168]. This means that buildings with solar panels and heat pumps report lower energy consumption since the energy consumption does not include household electricity use [168]. However, if the use of the heat pumps do not coincide with sunny periods, more electricity is needed from the grid without this affecting the annual energy consumption. In the Swedish environmental building certification Miljöbyggnad, energy consumption is one important aspect [169] and building owners strive to achieve a high certification level.

[18]For the stop date of the electricity certificate system, see Section 2.4.2.

[19]White certificates are energy efficiency obligation schemes imposed by the European Commission in the EED, where electricity producers has to ensure their consumer reduce their power consumption and increase energy efficiency. As Sweden could prove an equal reduction by other measures to the Commission, Sweden is exempt from the obligation and does not have white certificates today [170].

[20]In the EED, the European Commission requires individual measurement and debiting of energy, something that Sweden has previously not required from its building owners. After insistency from the Commission, Sweden eventually adapted a modified version of the obligation at the end of 2019, where only larger apartment buildings are included [171].

Possibilities with bioenergy

There is a consensus on bioenergy playing a substantial role in the future energy system, especially in Sweden, which is expressed by several interviewees as having unique advantages for bioenergy. Some of these advantages are resources like forests, hydropower and wind, knowledge and know-how, young and fertile soils and a mindset that differs from the rest of Europe, with resource efficiency and the Law of Jante. There is also a consensus that other countries have different possibilities of transitioning to a more biobased system and that the key to success is to optimise each system based on local conditions.

The interviewees agree that bioenergy fuels should come primarily from byproducts and waste streams and not from virgin resources, promoting higher-value products and circular economy as far as possible and seeing energy recovery as a final step. One bioenergy provider however believes byproducts will not suffice, but that there will be a need for cultivation of dedicated energy crops including woody crops in the long run. Several actors advocate for the substitutional effects that come with replacing fossil products with biobased ones, such as building material and packaging. Two substitutional effects apart from reducing the need for fossil resources is the sequestration of carbon in products and leaving space for new trees to grow and absorb CO_2, as exemplified by one bionenergy actor. An expanded use of biobased products will furthermore result in increased byproducts for energy purposes, contributing to the phase-out of fossil energy fuels. One bioenergy actor accentuates that one substantial strength of bioenergy is the versatility of biomass that can be converted with different techniques to different forms and be used in diverse applications. Another bioenergy provider adds that in the future, products and techniques will arise which are not known of today. An additional strength lifted by a third bioenergy actor is the end-of-life uses as biochar or bio-ash. An observation made by some interviewees is that the increased use of biomass in products might result in less quantity and lower quality fractions available for bioenergy but since there will always be byproducts they do not see this as an obstacle.

An advantage of bioenergy expressed by some interviewees is the storability at a low price, as opposed to wind and solar power that are instantaneous energy resources. One energy actor regards bioenergy as a storage tank for solar energy and one academic states that forest residuals and pellets are the cheapest options to store, followed by biogas and lastly bio-oils that risk to be decomposed by bacteria. When it comes to biogas, several interviewees believe it will play an important part in the future energy system since it can be produced from different biomass resources and be implemented easily in the current infrastructure. Gasification of biomass can further increase the electrical efficiency in biomass-fueled power plants according to one bioenergy provider[21]. One academic refers to the GoBiGas project as a success in demonstrating that gasification is technologically feasible even in a large scale. Concerning biogas from fermentation, one environmental actor believes that algae will contribute to increased biomass resources in the future. Moreover, some interviewees highlight the concern caused by the Swedish biogas support and lift that Danish biogas gets double support, thus outcompeting Swedish biogas.

From a social perspective, several interviewees agree that bioenergy can have favourable effects, mostly due to the creation of continuous employment and income which is of particular importance in developing countries. One of them compares with solar and wind power that create employment on the production site and during installation but that only requires rare maintenance once in operation. An aspect applicable to the Swedish system, as expressed by one energy actor, is that mills, factories and other biomass industries should be preferred in the vicinity of the resources to limit transportation.

[21] For more advantages of biogas, see Section 2.1.1

With the location of the resources in Sweden not corresponding to where most people live, efforts need to be put in rural affairs and regional growth. One bioenergy provider refers to bioenergy as contributing to the SDG's in more ways than social and ecological and elaborates on the aspect of clean water and air. They state that in Sweden, there are high restrictions on emissions that are met by our industry, but that bioenergy in developing countries needs technology development to ensure sufficient flue gas treatment to avoid nocive emissions.

Challenges with bioenergy

One aspect of bioenergy is whether or not it is to be seen as carbon neutral, which is discussed by several interviewees, most of them academics. The interviewees express that with responsible and sustainable forest management and farming, this is true, but that it is a complex question that depends a lot on the system boundaries used when looking at it. One energy actor states that it would be devastating for countries like Sweden with considerable biomass resources if bioenergy was not considered carbon neutral. Another aspect connected to the combustion of biomass is emissions besides CO_2, primarily NO_x and particulate matter, which can have other effects that need to be considered, according to one environmental actor.

There is a lot of discussions internationally concerning bioenergy and its role in the transitioning, where other countries often differ from the Swedish perspective. Several interviewees express the difficulty in having balanced discussions when the parties have different views, possibilities and needs, which for example is the case in the EU. One of them observes that the future development of bioenergy and the energy system will be more diversified based on local conditions, something that impacts which policy instruments are used in different countries. Several actors, mainly bioenergy providers, address the environmental movement in the EU as potentially hindering the development of biomass since it claims bioenergy is not compatible with the preservation of biodiversity. The actors add that people tend to remember bad examples and extrapolate the consequences to other bioenergy systems, such as palm oil plantations causing deforestation of rainforest or eucalyptus monoplantations for energy purposes. It is important but sometimes challenging to communicate the difference between different bioenergy systems and the benefits following the use of byproducts from Swedish forestry and agriculture, according to one academic. They add that the bioenergy sector needs to step up their communication game with both society and research. A couple of interviewees further express the need for supervision of bioenergy to ensure sustainable practices, especially concerning import from countries with less progressive regulations.

Some interviewees raise the question of availability of biomass and how much can be provided, which will depend on the demand from the different sectors. A few of them claim the forest can supply a large share but that it will not cover all the needs. On the other hand, a bioenergy provider claims all countries have much larger biomass potentials than they will admit today and that the difference between countries is in fact not so substantial. Some other actors state the importance of the free market and to let it dictate the distribution of biomass in a cost-effective way, leading to increased development and competitiveness compared to a situation where politicians decide which technologies and sectors to support with different policy instruments. Two interviewees advocate for tax exemption on sustainably produced biomass as a means of helping the market promote what is most beneficial. An issue that might arise, as expressed by one environmental actor, is if the production capacity of sustainable biomass is overestimated and too many investments are made, resulting in depleted resources, undermined sustainability and ultimately stranded assets. However, a few actors, mainly bioenergy providers, believe that the Swedish biomass potential is not used to its full potential and they wish to increase Swedish production to reduce reliance on import.

Some bioenergy providers see economical aspects as challenges to bioenergy development. There is a need for technical development which often depends on the amount of money available. One of them adds that if the cost of transport increases due to a changed transport sector there might be fewer incentives to increase the quantities of biomass harvested. The efficient use of resources is another aspect, raised by one academic. They note that fossil-based products have a high conversion efficiency and require less raw material compared to the same product based on biomass, indicating that replacing all fossil-based products with bio-based would require immense amounts of biomass which they acknowledge as a hard nut to crack.

Biodiversity and environmental aspects

Environmental aspects of bioenergy, such as biodiversity and ecosystem services, are identified to strongly affect the discussion on bioenergy. While solar and wind power are unconditionally renewable sources of energy, one academic states that bioenergy is only renewable when cultivated in a sustainable manner, and several actors accentuate the sensitivity of the bioenergy systems. They fear effects on biodiversity caused by both climate change and too extensive production. Other negative effects identified are infestations and damage caused by wildlife grazing. However, one of them, a bioenergy provider, states that focus should be on sustainably developing biodiversity and creating beneficial conditions for evolution instead of aiming to recreate what is lost. Many actors address the potential conflict between production and protection and they express the need for sustainable production to not jeopardise biodiversity and survival of the ecosystems. Several believe the conflict is solvable and that both climate goals and other environmental objectives need to be fulfilled at the same time. Several other actors accentuate that climate and other environmental goals should not be contradictory to developing biomass production but that they need to be considered simultaneously. One of them lifts the aspect of intensive cultivation in one place to protect another and expresses the challenge in deciding which areas to protect and which to sacrifice. One bioenergy provider summarises by claiming that the way society views bioenergy will affect its role in the future, whether it is considered as nature to protect or as living solar accumulators to benefit from, where this actor advocates for the latter. Another bioenergy provider agrees and adds that when looking at Earth as a system, the only input is solar radiation why the green industry is indispensable.

Forestry

There is an overall consensus on forestry being a key supplier of sustainable biomass in Sweden. Several interviewees declare that it is possible to increase both production and carbon sequestration in the forests but underline, as previously mentioned, the need for sustainable management. Together with some other actors, they raise the aspect of preservation and protection of biodiversity as hindering the development and convey that some parts of society discourage production and prefer forests to grow. One environmental actor conveys that both sides are right based on their assumptions and others agree that time and system boundaries affect the interpretation of a given system. However, the environmental actor advocates for longer cycles in forestry, and thereby letting forests accumulate carbon for a longer period before harvesting. This interviewee claims that this would be beneficial in the short-term from a climate mitigation perspective and also from a biodiversity perspective. Some actors, primarily bioenergy providers, state that non-managed forests will stop growing sooner or later, thus ceasing to sequester carbon. One of them accentuates that if Sweden lets its forests grow, the decrease in biomass availability will increase the demand for imported resources. However, two environmental actors fear that an increase in production will cause negative effects, regardless of acknowledging responsible and sustainable forest management in Sweden. Some interviewees discuss whether or not forestry in Sweden should be seen as plantations or natural forests and they differ in opinion from yes, Sweden has large shares of planted forests, to a mix of both, where the latter addresses overall environmental considerations even in the planted forests[22].

The conflict between the forest industry and the environmental movement is raised by several actors, especially regarding the EU. Some actors applause the Swedish Forest Agency on assuring sustainable forestry in Sweden, but as mentioned above, many interviewees acknowledge the different conditions in different countries and state that most European countries lack forests, resulting in divergent opinions concerning forestry. Nations with small forest resources are inclined to promote the preservation of forests instead of using them, affecting the political discussions in the EU. Several actors perceive an entailed risk of the EU restricting or even preventing development and expansion of bioenergy production in Sweden, even for systems that are considered sustainable in Sweden. An energy actor elaborates on the uncertainty created by the EU's changing view on sustainable biomass production, bioenergy and biofuel use, and remarks that this characterises how people perceive the role of bioenergy in the fossil free transition, in accordance with previously mentioned opinions on this matter (see Section 4.1.2). An academic adds to this and highlights how the high media coverage of unsustainable bioenergy systems harms the growth of sustainable bioenergy systems by unproportionally skewing politics to more rigorous regulations. All this leads several actors to express a need to protect and advance Swedish interests concerning forest management and biomass use within the EU, as mentioned in Section 4.1.1.

The same strong forces in Europe against biomass use affect the forestry sector by obstructing bioenergy use, according to a couple of actors. One academic states that the largest threat to Swedish forest management is the EU starting to regulate forest management, regardless of Sweden and Finland accounting for the largest of the EU forests[23] and thus also holds the forest competence and know-how. In agreement with another academic, they both promote letting the forest-dense nations collaborate on regulations instead. A third academic expresses frustration over Sweden not looking after its possibilities, which a bioenergy provider agrees on and states Sweden has not been sufficiently convincing when discussing forest management and sustainability. As Sweden and Finland are forest-dense but population-sparse, this actor signifies that the Nordic views on forest management do not generate the impact they should. They further state the EU way of managing forests will release carbon in the long run, as they are not properly managed and thus will cease to sequester carbon. Another bioenergy provider remarks that even if each nation officially determines its own forest policies, it is only partly true since the EU has integrated forest issues into climate issues and this actor emphasises the importance of letting Sweden decide on its own forest policies. A third bioenergy provider claims Sweden has done a quite good job so far in dodging micro-management on forestry, but sees that the other side will keep fighting for their cause. On the other hand, an energy actor conveys EU forest regulations will not largely impact Sweden since there are already adequate regulations here. Moreover, the first academic notes that considering the current COVID-19 crisis, the EU has more pressing issues to handle than to micro-manage Nordic forest management. A bioenergy provider concludes by accentuating that all political decisions limiting the possibility to utilise forest material also restrict bioenergy use.

As previously mentioned, bioenergy should primarily come from byproducts, and the availability of biomass for energy purposes in Sweden is driven by the timber, paper and pulp industries. Many interviewees, mostly energy and bioenergy actors, express the potential of increasing the use of forest

[22] For more information on Swedish forest management, see Section 2.4.2

[23] According to Eurostat, in 2018 Sweden and Finland together account for a third of EU's forests and wooded land (54 million hectares out of 182 million) [172].

residuals for bioenergy purposes[24]. A few actors, mainly bioenergy providers, state that the outtake is hindered by demand and profitability rather than ecological constraints, and add technical issues such as ground damage during outtake as another hindering aspect. One bioenergy provider expresses that in a scenario with rising costs of waste incineration or increased numbers of bio CHP plants, the exploitation of forest residuals would become more profitable. This connects to the discussion of CHP plant's profitability in Section 4.1.3, where the actor sees this as more of an issue than the profitability of extracting the forest residuals. A couple of interviewees suggest alternative uses of forest residuals and one of them exemplifies with biofuels, but questions the efficiency with current technology. One environmental actor accepts limited use of tops and branches from the forest, but objects to stump removal, for reasons of maintaining biodiversity and soil integrity including nutrient recycling. Together with one energy and one bioenergy actor, they all identify issues with ash return, such as ensuring that the ash can be recovered without contamination and technical constraints connected to the returning process, and once again the question of profitability is central.

Agriculture

Focusing on the agricultural contribution to bioenergy, the question of competition between bioenergy crops and food production inevitably surfaces. Many actors emphasise this should not be viewed as competing nor as a problem, seeing as food crops generate inedible residues and as Sweden has fallow land that could be used.

Starting with food crops, two actors claim there will be an increased production of domestic foods. Of these two, a bioenergy provider state there is a will to increase production among Swedish farmers and an academic believes the support for this will rise. They both highlight that increased food production implies increased residues and intercrops for other purposes and both promote a circular bioeconomy. Two other actors accentuate that different fragments of the same crop can be used for separate purposes and states that no food crops are entirely edible. One of them, a bioenergy provider, problematises the EU's peculiar need to classify crops as either food or energy crops[25] and states cheap food will cost us big, while the other actor agrees the EU has strong protectionist traits when it comes to farming. Multiple other actors agree that the EU blocks development of energy crops since there is a strong opposition in the EU to use arable land for energy crops causing over-legislation. The bioenergy provider continues that it is better to let the market decide what to do with the residues, be it vegetarian proteins, animal fodder, biofuels or bioenergy.

Continuing with arable land, two actors argue that growing energy crops allows for easy and quick returns to food production if that should be needed. They mean that if the area instead is bound up to longer use, such as energy forests of willow or poplar, or even converted into urban areas, it is much more difficult to switch back to food production. One bioenergy provider believes fast-growing, nutrition-dense and surface-effective crops will rise in interest and wonders how people will regard thick walls of willow on the formerly open landscapes. Another actor wonders over the future consumption pattern and sees a trend towards vegetarianism, which they mean implies more potential for energy crops as most grown crops today goes to animal feed[26]. Concluding the discussion of food versus energy crops, one energy actor claims this is already fully debated since a few years back, as it

[24] In a 2016 report on the potential of Swedish biomass production, the potential increase of forest residuals outtake is stated as 33-36 TWh/year, with ecological restrictions taken into consideration [142].

[25] The RED II sets a limit on the production of biofuels, bioliquids and biomass fuels for transportation from food and feed crops to a maximum of 7% of final consumption of energy in the road and rail transport sectors in each member state [14].

[26] The Swedish Federation of Farmers (Lantbrukarnas Riksförbund) states in a Q&A from 2018 that 80% of what is grown in Sweden is used to produce animal feed [173].

could be proven energy crops are not what causes famine, poverty does[27].

Turning to Swedish farmers, one bioenergy provider elaborates on their importance and excellence. This actor implies the Swedish farmers are among the best in the world and highlights pork production as being the very best in the world[28]. By this, they argue Sweden should increase the meat production and export to other nations, both due to the excellent production standards and to Sweden having large areas of grassland which are unsuitable for other uses than animal grazing[29]. Further, this actor emphasises the importance of raising both the pride and profitability in farming in order to keep farmers in the trade. The actor sadly remarks 3-4 farmers quit each day[30], as they can no longer cope with the harsh critiques and having their children being bullied in school. The bioenergy provider problematises this both as they see Swedish farmers doing admirable work and as this sends an unfortunate signal to other countries on following Sweden's good example concerning animal husbandry and environmental consideration. In addition, they convey Sweden seems to have amongst the most fertile soils in the EU in the future[31], making it even more important to preserve and support Swedish farmers.

As a last comment, one energy actor believes the agricultural sector will have the hardest time to become fossil free in Sweden and promotes policy instruments such as the Reduction obligation since this allows adapting it to what suits one best.

Waste

When it comes to waste incineration, none of the interviewees is strongly against it, although some advocates that it needs to be dismantled in the long term. Many agree the main problem is not the incineration in itself, but instead the occurrence of waste along with people's consumption and recycling patterns and the lack of a circular perspective in industries and society as a whole. Accordingly, many believe it is important to work with the waste hierarchy, described in Section 2.1.1 (see Fig. 2). A few interviewees promote waste incineration in itself, either to prevent landfill or to dispose of hazardous waste. Others agree landfill should be avoided but promotes instead preventing the occurrence of waste and increasing reusing and recycling.

Considering that Sweden has a high heat demand and an elaborate DH system, some interviewees support the import of waste from other countries. They argue there is still a need to treat waste by incineration, that Sweden has both the capacity and demand for burning waste for heat and as such

[27] According to the global aid organisation Oxfam, famine is not caused simply by a lack of food. Instead, multiple factors contribute, where they highlight "poor (or even intentionally bad) policy decisions that make people vulnerable" and state the people most at risk are the poorest and most vulnerable [174].

[28] The Animal Protection Index ranks Sweden as having among the best animal husbandry in the world [175] and states "Swedish animal welfare legislation goes beyond and above EU law"[176]. Concerning pig farming, highlighted exemplary practises are the prohibition of both tail docking and sow-fixation, where for the latter sow and piglets are instead allowed to stay in larger open boxes [176, 177]. On the other hand, the Swedish animal rights and animal welfare organisation Djurens Rätt notes that almost all Swedish pigs spend their lives indoor on concrete floors deprived of their natural behaviours [178].

[29] According to Swedish Statistics, SCB, the Swedish area share of agricultural land accounts for 8% of which 15% is pasture. Another 8% of the Swedish land area consists of natural grasslands that are currently not used for any economic gains. To contextualise only 3% of the land is built on and recall 70% consists of forests [179].

[30] A 2019 study on the future of agriculture from the Swedish University of Agriculture states that a third of all farms in Sweden have disappeared in the last 25 years [180]. The amount of employees in agriculture has decreased with 7510 people between 2010 and 2017, corresponding to 4% [181], which Spread out over the total number of days corresponds to approximately 3 farmers quitting per day.

[31] Naturvårdsverket states that the climate change-induced warmer temperatures in Sweden can increase the farming conditions in the future, thus generating higher yields in both forestry and agriculture [182]

can help other countries become more circular in their waste treatment by offering energy recovery. On the other hand, one energy actor notes that waste could outcompete national biomass resources. Some actors are more concerned about the import, and see a problematic in importing waste since it is generally un-sorted, thus containing a lot of fossil-based items, namely plastics. The fossil part of waste is a common concern for several actors, regardless of their opinion on waste incineration itself, either since it causes fossil emissions or since it means people have not recycled thus preventing material from being reused. Some point out there is no market value in recycled plastics both due to virgin oil being cheaper and to the plastic losing in quality by material recovery. In addition, a bioenergy provider states there are no requirements nor incitements for plastic producers to create plastics that can be recycled since they are often not included in the Swedish producer's responsibility[32]. On the brighter side, two academics state it is possible to gasify plastic waste at high temperatures into raw material for new plastic products, one of them highlighting the ongoing initiative with chemical recycling[33]. The same academic elaborates recycling is but a mere definition; everything can be recycled, it is just a matter of cost and societal will.

Even though many express frustration over people's inability to properly recycle, one bioenergy provider highlights that from an international perspective Sweden is quite good at recycling. However, they believe a lot more could be done, especially concerning industrial waste since this tends to be badly sorted. On the municipal level, it is hard to get more individuals to recycle since those who want to already do and those who do not recycle will not start either. Another actor lifts the indistinct opinion of consumers wanting to buy heat produced from their own waste but not from imported waste, implying a need to market waste incineration more as a destruction service. As for the European perspective on waste incineration, two bioenergy providers express frustration over some European countries' recalcitrance. One lifts the Italian zero waste initiative[34] and complains about their way of calculating what counts as recycling, as Italy has several Mechanical Biological Treatment plants[35], which this actor claims do not properly recycle even though Italy counts it as such. The other one highlights the UK and Germany, where organisations who are strict opponents of waste incineration block any investments or projects on this[36], as they believe waste incineration causes too high levels of dioxins, which the actor states as ignorance since Sweden has almost eliminated dioxin emissions[37].

[32]The Swedish producer's responsibility covers eight product groups; batteries, cars, tires, electrical equipment, packaging, waste paper, medicines as well as radioactive products and stray radiation sources [183]. Thus plastics outside of all of these groups are not covered.

[33]The chemical industries in Stenungsund have come together in a vision for sustainable chemistry by 2030. As a part of this, they investigate a recycled-plastics refinery and has created a roadmap on how to achieve it [184].

[34]The zero waste movement aims to eliminate all waste in society by empowering consumption pattern changes towards circularity [185]. The European movement sprouted in the Italian town of Capannori in 2007 [186].

[35]Mechanical Biological Treatment (MBT) plants treat municipal solid waste by mechanical separation of recyclables and biological treatment of the organic fraction, either through composting or anaerobic digestion. The MBT plants recover some recyclables and reduce the amount of waste that is sent to landfills, especially the biodegradable fraction. The plants also generate so-called refused derived fuels that can be used in incinerators or cement kilns [187].

[36]In the UK, there is an organisation called the United Kingdom Without Incineration Network (UKWIN), which is a strong opponent of waste incineration and campaigns for anti-incineration. Since its founding in 2007, it has prevented numerous waste incineration plants in the UK [188]. Germany has no counterpart to UKWIN, but the environment association NABU (Naturschutzbund Deutschland) seeks to reduce the need of waste incineration in Germany and promotes instead reuse, recyling and circular economy [189].

[37]In the period 1990 to 2018, the Swedish dioxin emissions in the industrial sector reduced with 87% [190]. Note that the debate on dioxins arose already in the 1980s, why reductions where done already before the start of this statistic. For comparison with earlier statistics, the Swedish Food Agency notes a 90% decrease in dioxins in breast milk between the 1970s and 2016 [191]. In addition, with the dioxin removal technology ADIOX, the dioxin concentration in flue gas can be reduced to below 0.1 ng toxic equivalents per normal cubic meter [192].

One of the environmental actors is critical of the Swedish model of waste incineration in itself since they argue the model is built upon other countries performing badly in their circularity so that Sweden can import their waste for heating. Building on this, they mean the Swedish model does not work on a system level because if all countries followed the Swedish model, it would not work anymore since there would not be enough residual waste. An academic points out that most DH systems in Sweden would make do without waste incineration, utilising lower grade heat instead. However, they further underline the strong local financial importance of waste incineration as it generates double income by accepting waste at a charge and selling DH, thus making it an important money-maker for municipalities and energy companies.

As mentioned in Section 2.4.2, a tax on waste incineration was implemented in the spring of 2020. Multiple actors express their discontent claiming the new tax is bad and misses the point. They agree that the tax creates strange incentives since it favours not sorting out plastics due to it being set per tonne and the fact that plastic waste has a higher heating value than ordinary waste. Thus, the tax misses the point since its goal is to reduce the fossil content of waste and increase recycling. One actor highlights that the tax will never affect those who choose to not recycle, thus never enabling behavioural changes. This actor promotes instead a tax on plastic granulates, which they mean will transfer the cost to the producer who is responsible and can actually make a change by rising the product cost, which the actor states is not possible for DH providers. Another one states it would have been better to start with a policy instrument in the other end, promoting material reuse and incentivising a market for recycled materials but also emphasises that it is important to do something to decrease the fossil plastic in waste. Moreover, a couple of actors perceive no one really wanted the tax in the first place; one points out the government's own investigation dismissed the tax as ineffective[38] and another one states even politicians are unenthusiastic when inquired about it.

Transport sector

Even though the bioenergy use in the transport sector is not part of the scope for the thesis project, it sometimes surfaces when talking about other bioenergy uses. Thus, about half of the interviewees gave responses concerning the transport sector, its development and the role of biofuels in the transitioning to fossil freeness.

Of these respondents, there is an overall consensus that the transport sector is a challenge for fossil freeness and that there is a need for technical advancement, in second and third generation biofuels as well as in electrification, batteries and hydrogen. One actor adds onto this with another facet for achieving sustainable transport; a transport-efficient society. They mean this is a key challenge that requires complex system solutions, spanning over several actors, companies, regions and even countries, in order to maintain the current availability but with less transportation. Several interviewees express concern about the uncertain conditions in the development of the transport sector. As for policy instruments regarding the transport sector, a couple of interviewees suggest letting the market decide which technology to promote and lifts possible market failures appearing from micro-management from politicians. One underlines it is important that politicians do not subsidise solutions that are not sustainable over time, even if they are good transitional solutions. On the other hand, another actor believes strong policy instruments are required to change and develop the transport sector.

Several interviewees see biofuels as an important step towards achieving a fossil free transport industry since this transition can be done today with existing infrastructure. After the transition, some still

[38] See Section 2.4.2 under "Taxes and energy-related policy instruments".

see a role for biofuels in heavy transport and cargo and one of them stresses the importance of using biofuel efficiently and only where it is needed. One environmental actor emphasises that the time for first generation biofuel is over and that it is now time for other solutions. Other interviewees covering all actor categories express enthusiasm over the possibilities of hydrogen in the transport sector. One academic elaborates that hydrogen may be used directly, but may also be combined with CO_2 produced from other biomass industries to form renewable liquid fuels such as methanol. This may add another role to biorefineries. All agree on hydrogen as a young technology with large potential. Most find the technical advancements hard to predict and believe that hydrogen could take the market by leaps and bounds once the development accelerates. A couple of interviewees state wind power as the ideal source for hydrogen production.

A couple of environmental actors advocate electrification where this is possible while an energy actor notes the transport sector, along with other sectors, underestimates the role of electrification and sees the entire transport sector will not be fueled by bioenergy. Another couple of interviewees express criticism against electrification, and especially locking oneself into electrification as the sole solution. One also lifts the sustainability aspect of batteries and their dependence upon rare minerals. Another interviewee believes the price of batteries will fall once they are part of a circular economy with recycling and also pushes the need for battery production in Europe to keep competitiveness in the transport industry.

4.1.5 Carbon capture and storage

This section presents the interview responses concerning carbon capture and storage along with its possibilities and challenges. There are interviewees both in favour of CCS and those more reserved, and almost all convey challenges and difficulties.

Possibilities and challenges with CCS and BECCS

Those in favour of CCS consist mainly of energy actors and bioenergy providers, and they argue that it is necessary to remove CO_2 and highlight the possibility to combine CCS with large point emitters or with industries for which transitioning to carbon neutrality is not possible (e.g. cement industry or waste incineration). Several actors see regular CCS as a bridge to BECCS and a few argue that the burden and cost of developing the technique for CCS need to be carried by the industries that cannot transition. One of the bioenergy providers emphasises BECCS as the only available technology to offer CO_2 reduction from the atmosphere at a reasonable cost and points out Sweden's unique possibilities for this. One of the environmental actors agrees BECCS could be used to reduce CO_2, but that it is important to ensure it is done sustainably, with fast-growing crops rather than natural forests. They further emphasise that it needs to be BECCS and not CCS on fossil sources as an excuse for business as usual, claiming that the latter would be counterproductive. Another environmental actor lifts the problematic of area requirements for BECCS if used with dedicated crops, which would amount to an area almost twice the size of India[39]. This type of thinking is lifted as one of the challenges for BECCS by the same bioenergy provider, who stresses that BECCS should not be used by simply growing and burning biomass to capture CO_2, but instead to use the biomass for other, necessary primary uses such as timber, paper and pulp industries or heating and electricity, after which the CO_2 can be captured from flue gases.

[39] An article from 2018 on the problematics of BECCS by the European environmental organisation Fern states an area requirement of 1-2 times the size of India (0.1-0.4 ha per tonne carbon removed, i.e. 380-700 million ha) to stay below 2°C of warming [193].

Two other interviewees in favour of CCS state it as a technique and as such not something that anyone can be against. However, one of the environmental actors is strongly against CCS and does not that believe it will work in full scale nor with storage, and sees CCS as an excuse for fossil emitters to keep on business as usual. A few other actors also express concern regarding business as usual and the reliability of the CO_2 storage. Also, some of those in favour of CCS see the transportation and storage of CO_2 as big challenges, with both technical, safety-related and financial aspects. Two environmental actors promote instead leaving forests be to accumulate carbon, stating it as a cheaper, well-tested and proven option[40]. One of the bioenergy providers agrees this is a common opinion but states that it as a dangerous one, as they believe it is harmful for the forest production in a long-term perspective to bind carbon since this creates models where the forest can never be harvested without causing large releases of CO_2[41]. This belief is shared by another bioenergy provider, and they both problematise what happens with the accumulated carbon if one keeps adding in more biochar until oversaturation or in case of natural catastrophes such as wildfires and how this should be accounted for. Another of the environmental actors emphasises the importance of a system perspective of forestry, where the start of the timeline is set for carbon accumulation and what differences this makes. Further, they problematise the overreliance on forest production systems and the risks of sensitive systems this creates, with monoculture, weak resistance to pesticides and climate change, which they believe could backfire on the forest productions.

Financial aspects and policy instruments

Several actors are agreeing CCS and BECCS is currently too expensive and does not generate any profit for the plant owner. In this context, aspects of cost and energy efficiency, security and return of investment as well as technical challenges are lifted. Most of these actors also agree policy instruments and/or financial support for CCS and BECCS is required to take the leap to commercial use. Out of these, three express a strong belief of these kinds of support appearing in the near future. Of these, a bioenergy provider is certain large point emitters of biogenic carbon such as pulp industries will be heavily courted by politicians on this matter, an energy actor speaks of an upcoming proposition of reverse auctions where the one able to construct a CCS plant at the lowest cost will get some reimbursement[42], and lastly an academic believes interim supports for CCS investments will definitely come to help commercialise the technique. In addition, another energy actor is hopeful in this matter and claims the government is aware of the need for CCS support and that it is as under consideration due to this.

Miscellaneous opinions on carbon capture

One bioenergy provider thinks it would be better to utilise the CO_2 after spending so much energy and resources on capturing it, rather than just storing it underground. To justify the potential use of the CO_2 captured and converted to products, it would have to increase the climate efficiency of

[40] According to a 2011 report on boreal forests in a climate perspective made in collaboration with WWF and Naturskyddsföreningen, there are three main ways of using forests and forestry to handle carbon flows. First, protecting forests in order to leave them to grow and thus accumulate carbon. Second, managing the forest in a way to help it bind more carbon by e.g. fertilization and third, substituting fossil raw material with biobased material. Here, the first option is stated as the most effective [21].

[41] According to an article by the Swedish forestry sector's research body Skogforsk and two Swedish universities, it is expensive to increase carbon sinks by leaving forests standing. They performed calculations on the additional value of 10, 20 and 30 years of extra growth time and found it would be more cost-effective for the forest owner to buy ETS permits. They further found increasing the forest cycle with 30 years would generate an addition of only 0.05 - 0.20 tonnes of carbon per hectare [194].

[42] See Section 2.1.2.

the economic system as a whole. Two interviewees mention DAC while discussing CCS and BECCS. One points out the energy inefficiency of current DAC technologies and promotes BECCS instead, the other is excited about DAC but does not see it as a viable option for Sweden, but rather in deserts run on solar cells. One academic points out the tediousity of BECCS and argues that fossil energy carriers have higher energy efficiency than virgin biomass, so to fill an energy need, fossil fuels would be more effective. They further state all types of CCS are the same, once there are emissions caused by a proclaimed resource, it does not matter if it is fossil or biogenic, the CO_2 emissions are there nonetheless. One environmental actor claims society is already too far down the line, all modeled CCS and BECCS pathways to keep warming below 2°C require we started yesterday with several, full-scale CCS. Thus, they mean society is behind on implementation, living in the pathway scenarios but not keeping up, implying there is a dangerous societal overreliance on BECCS as a silver bullet solution.

Lastly, some other aspects tangenting CCS and BECCS are lifted in the interviews concerning what negative emissions really are and how these should be evaluated as well as the difficulties in predicting technical advancements.

4.2 Policy landscape

This second result section presents a policy landscape with existing policy instruments along with those currently on the horizon for implementation in both Sweden and the EU. The landscape presents instruments found through literature study and the comments are based partly on what can be found in official documents and to some extent on the interview responses where either several actors see similar tendencies or where individual actors are fairly certain of the development. As far as possible, interview responses are cross-checked with additional literature study. As no one can know what the future holds, these predictions are only guesses, albeit qualified, which brings this result section border to discussion on the future of the environmental policy instruments.

The policy landscape is divided into subsections based on the type of policy instrument, following the categorisation presented in Section 2.4.1. Each section includes a table (Table 5-7) presenting policy instruments of a specific type, all following the same structure. In the leftmost column, the instruments are named along with a note on whether they are EU or Swedish instruments. The middle column shortly describes the function of the instrument and the last column offers a speculative comment on future development. The order of appearance of the policy instruments follows partly a division between the different categories and partly a logical order for further description beneath the tables. At the end, a policy timeline stretching to 2050 is presented.

4.2.1 Direct regulations

The direct regulations account for the largest share of policy instruments, mainly by laws and EU regulations, as presented in Table 5.

Table 5: *Presentation of direct regulations where the left column presents the policy instrument along with a note on if it is EU or Swedish, the middle column presents the function and the last column offers a speculative comment on future development.*

Policy Instruments		**Function**	**Comment**
Climate law	EU	By 2050 all members shall have net zero GHG emissions.	Will remain.
Environmental Code	SE	The core of Swedish climate legislation; promotes sustainable development.	Upcoming revision of the Species Protection Regulation by 2021. Might also come additions of GHG emission consideration in the Specific environmental assessment at Licence probations.
2030 Climate & energy framework	EU	40% reduction of GHG emissions, 32% share of renewable energy, 32.5% improvement in energy efficiency by 2030.	The commission aims to raise the GHG reduction target to at least 50% with the 2030 Climate Target Plan. Probably new framework with new targets for the next decade.
Effort sharing regulation	EU	Reduction of emissions from non-ETS sectors with 30% by 2030.	Part of the long term strategy. Might be revised in 2021 due to the 2030 Climate Target Plan.
LULUCF regulation	EU	Emissions from the LULUCF sector shall not exceed removals for the periods 2021-2025 and 2026-2030.	First inclusion of LULUCF in EU law. Might be revised in 2021 due to the 2030 Climate Target Plan. Likely new targets will be set for the coming decade. Might spark new discussions on the topic.
RED II	EU	Framework for promotion of renewable energy with binding target of 32% renewable energy by 2030.	Transposition into national law by 2021. Uncertainty on how the implementation will turn out and how it affects. Might result in more defined regulations on sustainable biomass production which could affect bioenergy development. Might be revised in 2021 due to the 2030 Climate Target Plan.
Reduction obligation	SE	Obligation to increase the share of renewable fuels.	Will remain.
Forestry Act	SE	Regulates Swedish forest management.	Will likely be altered to give larger rights to environmental protection in the coming years, induced by ongoing investigations.
CAP	EU	Agricultural policy.	Set to tend more to the agricultural sector's role on climate mitigation for the period 2021-2027.

Both the EU Climate law and the Swedish Environmental Code are stable environmental policy instruments that will remain. There are no predicted surprises for the EU Climate law. The Environmental Code on the other hand is facing possible changes. Firstly, there is an ongoing investigation that revises the Species Protection Regulation which will be finished by 2021 [195]. After this more ponderosity will likely be given to environmental and species protection. Secondly, the Code might be expanded to include GHG emission consideration in the Specific environmental assessment at Licence probations, driven by the ongoing trial of the oil refinery expansion in Lysekil which at the time of writing awaits the final decision by the Government[43]. As one of the interviewees noted, this kind of trial has not been raised to government level before, and the verdict will be indicative for future environmental assessments of industrial operation.

The 2030 climate & energy framework succeeds the 2020 climate & energy package with new targets and with the 2030 Climate target plan, the Commission aims to increase the GHG target even further. As mentioned in Section 2.4.3, this might entail changes in both RED II, the effort sharing and LULUCF regulations in 2021. To reach the 2050 target, a new framework with new targets will most likely come for the next decade that will prolong the commitments in all climate regulations that currently end in 2030. There are no other predictions for the effort sharing regulation while the LULUCF regulation could spark new discussions as this is the first time this sector is included in EU law.

The upcoming transposition of RED II into national law in 2021 along with its implications on the definition of sustainable biomass concerns many interviewees, as mentioned in the interview findings. This definition will undeniably affect the development of biomass use, bioenergy as well as biofuels, in Sweden and the rest of Europe. Many interviewees, especially bioenergy providers and energy actors, worry that practises and biomass sources considered sustainable in Sweden will not be by the EU. A specific topic is biofuels and bioenergy from food-crops which at the moment does not look particularly promising[44]. On the other hand, the implementation of RED II could still benefit Sweden to some extent. If the sustainability criteria leads to stricter control of biomass origin in other European countries, they might want to increase their import of Swedish sustainable biomass, which could likely com from legally harvested forests.

The Reduction obligation is a fairly recent environmental policy instrument and there are no indications it would disappear, thus it is deemed it will remain which is also agreed by some interviewees. One even stated it could become the most important environmental policy instrument in Sweden along with the CO_2 tax. As mentioned, the Reduction obligation is supposed to increase the share of renewables in petrol and diesel to reach 70% decreased GHG emissions from domestic transport by 2030, which aligns with the national goal of a fossil independent vehicle fleet by 2030 [199]. It is possible the Reduction obligation will be renewed after this to reach net zero emissions from domestic transport by 2050.

The investigation on the Species Protection Regulation mentioned with the Environmental Code might also influence the Forestry Act to include more aspects of environmental and species protection.

[43] Sweden's largest fuel company, Preem, applied for an expansion to accommodate new regulations on treatment of heavy oil which was authorised in 2018 [196]. Naturskyddsföreningen opposed the expansion with its entailed increase of GHG emissions and appelead to the Land and Environment Court of Appeal (Mark- och miljööverdomstolen) [197]. In June 2020, the Court considered the expansion allowable. Due to the numerous appeals, the issue is now on the Governments table, and awaits their verdict at the time of writing [198].

[44] In the EU there is opposition against using food-crops for non-food purposes, as expressed by several interviewees. It is also signaled as the Commission indicates no State Aid for food-based biofuels will be authorised in Sweden beyond 2020 [92].

In addition, a separate investigation on forest management, ownership and biodiversity was handed to the Ministry of Environment on the 1st of July 2020 [200]. This will likely entail environmental protection is given larger rights, but could also lead to strengthened ownership rights and economic compensation for forest owners.

For the revision of CAP for the period 2021-2027, the European Commission has set nine goals, including inter alia adapting farming to combat climate change and to preserve biodiversity [201]. This revision will impact Swedish forest sector to some extent, however it is deemed the management of both the agricultural and forest sector will continue to be dominated by Swedish regulations.

4.2.2 Tradable permits, taxes and charges

This section presents tradable permits, taxes and charges in Table 6, where tradable permits are a policy instrument creating markets whereas taxes and charges are using markets.

Table 6: *Presentation of tradable permits, taxes and charges, where the left column presents the policy instrument along with a note on if it is EU or Swedish, the middle column presents the function and the last column offers a speculative comment on future development.*

Policy Instruments		**Function**	**Comment**
EU ETS	EU	Reduce CO2 emissions by cap and trade.	Permit allocation will gradually turn to auctioning until 2030. Price per permit likely to continue to increase. Possibly expand and cover more sectors in coming phase revisions.
Carbon/CO_2 tax	SE	Tax on the carbon content in fuels for heating and propulsion. In 2019 it corresponded to over 112 €/CO_{2eq}.	The CO2 tax will remain and continue to increase. Might include more sectors in the future.
	EU	Not currently existing.	The EU will likely adopt a common CO_2 tax in the coming years. However, the tax rate will most likely be well below the Swedish level.
Energy tax	SE	Tax on energy in electricity and energy products aimed for heating and propulsion.	Will remain and likely continue to increase as it has done previously.
Waste tax	SE	Tax on the fossil content of waste implemented in 2020. Current rate: 75 SEK per tonne waste.	Is set to step-wise increase until 2022 to 125 SEK/tonne. Could influence some sort of taxation/regulation on plastic producers in the coming years to target the root cause.
NO_x charge	SE	Charge on NOx emissions in flue gases in a REP-system.	Possibly increase in the years to come. Will likely not become a tax due to issues with EU State Aid rules. The refund of the charge might decrease or disappear to make it a pure charge.

As a part of the 2030 Climate target plan, the Commission might propose updates to the ETS already in 2021 to reach the stricter GHG emissions target. As mentioned in Section 2.4.3, the ETS will turn to pure auctioning by 2030. The price per permit will likely increase during phase 4 as the yearly cap on emissions will be increased to 2,2% compared to the current 1,74% [132], meaning the total amount of allowed emission decreases thus becoming more scarce and as such, usually more expensive. An actor mentioned the ETS could expand to include more sectors such as transport, buildings and agricultural sector. We believe it is likely this will happen eventually, however, there are no mentions of this in the current revision for phase 4 [132] why this might not happen until the next revision, of phase 5. On the other hand, other regulations might tend to these other sectors instead. Member states are allowed to voluntarily enter more sectors or small plants exempt from already covered sectors into the ETS, but whether this is likely or not is too speculative to discuss.

There are no predicted surprises for the Swedish CO_2 tax nor for the energy tax; they will remain and continue to increase. What might happen, is that the EU adopts its own carbon tax, or rather, a minimum level of which all member states need to implement national carbon taxes, as mentioned by two actors. As Sweden has the highest CO_2 tax in the world, it will likely take countless years, if ever, for the EU to surpass the Swedish level. Related to the energy tax, it is possible that the electricity tax for consumers changes to handle supply variations, meaning it would be cheap to consume electricity when there is abundant but expensive when there is not. In a report of the Swedish energy system and the climate goals from 2019 it is stated an increased demand flexibility is needed to meet the energy system challenges [24], however there are no mentions of a flexible electricity tax.

The recently implemented waste incineration tax will likely remain, regardless of its many opponents, not least among the interviewees. As the energy sector becomes entirely fossil free, the tax on waste incineration might increase even more as it then will be the only fossil content in the sector. However, as the tax on waste incineration has been found to not target the root cause of the fossil content in waste, other regulations will likely arise in an attempt to get the actual polluter, i.e. the fossil producer, to pay. Whether this will happen anytime soon is uncertain.

As mentioned in Section 2.4.2, the EU rules on State Aid makes it difficult to modify the NO_x charge without breaking the rules, why it will likely not become a tax. However, it could expand to include sectors that today are exempt and the part of the charge that is refunded today to those with lower specific emissions might be removed to turn it into a pure charge. As for the rules on State Aids themselves, one of the interviewees mentioned they have been somewhat loosened due to the crisis created by COVID-19 but believed they would be resumed again once the acute phase of the crisis is over. In addition, the member states got a new draft from the European Commission in May 2020, where the aim is “to streamline the State Aid rules” [202]. According to the European Parliament Think Tank, the Parliament wants the State Aids to support ecological transformation but also for them to be dismantled in the long term [97] while the European Parliamentary Research Service Policy Podcast believes the current rules will be prolonged another 2 years [203].

4.2.3 Targeted subsidies and voluntary agreements

This section presents targeted subsidies and voluntary agreements in Table 7.

Table 7: *Presentation of targeted subsidies and voluntary agreements where the left column presents the policy instrument along with a note on if it is EU or Swedish, the middle column presents the function and the last column offers a speculative comment on future development.*

Policy Instruments		**Function**	**Comment**
Electricity certificate system	SE	Production subsidy for new installations of energy from renewable sources.	Ongoing proposition to end new applications by the end of 2021 thus terminating the system by 2035.
CCS/BECCS support	SE	Not currently existing.	A targeted subsidy for implementing CCS is arising in the form of reverse auctions.
CHP support	SE	Not currently existing.	Although many energy actors wish for this, a tageted subsidy for CHP does not seem to be emerging in a near future. It might emerge some years from now.
Klimatklivet	SE	Targeted subsidy for local and regional physical climate mitigation actions.	Will remain.
Innovation fund	EU	Funding program promoting innovations of low-carbon technologies.	Will remain.
Roadmap for the Heating Sector	SE	Common voluntary agreement between energy companies to achieve fossil freeness by 2030.	Will remain.

Firstly, as mentioned in Section 2.4.2, the electricity certificate system is currently on its referral round on the proposition to end new applications in 2021 thus terminating the system by 2035. Several interviewees mentioned this and most agree the system has played its part. The system will likely be terminated as proposed.

The following two targeted subsidies are not currently existing. For CCS/BECCS this is however only a question of time. As mentioned in Section 2.1.2, the SOU on the road towards a carbon positive future suggests a reverse auction scheme for BECCS, which also some of the interviewees mentioned. The investigation further states the first plants need to be taken into operation during this decade and considering the lead time of implementation, the support scheme needs to be put into place as soon as possible [39]. Again, this is in accordance with interview responses why it is deemed this support scheme will enter into force shortly. In addition, there are various ongoing projects in Sweden, both on BECCS and CCS. To mention some, the energy company Stockholm Exergi launched a pilot BECCS plant in December 2019 [204], in May 2020 the oil company Preem launched Sweden's largest pilot CCS plant [205] and the cement producer and building material company Cementa has an ongoing CCS project where the possibility of storing CO_2 in the Baltic Sea is investigated [206].

A potential support for CHP on the other hand does not seem to be on the horizon yet. Several energy actors expressed a need for this, in order to preserve its important role as stable base load. In april

2020, Profu, an independent consultancy company in project-oriented research and development, released an investigation on the benefits of CHP [207], which might open policy-makers' eyes to the subject. Even so, a support scheme for CHP is likely still several years in the future. An issue that remains with power capacity rewarding is that it entails a debate on nuclear and hydropower and whether or not these should be included, as lifted by one interviewee.

The third targeted subsidy, Klimatklivet is existing, however it is dependent on the Government assigning money in the national budget for this purpose. In fact, the planned application round in May 2020 has been suspended, due money granted for 2021-2023 needing to supply already authorised actions [208]. Nevertheless, the subsidy in itself will likely remain even though the amount of available grant money will vary. The last targeted subsidy, the EU Innovation fund, is deemed to remain with no predicted surprises.

Finally, the voluntary agreement of the Heating sector has no predicted surprises either. The Roadmap to achieve fossil freeness by 2030 will remain and could entail further collaborations between energy companies as well as new targets in the future.

4.2.4 Policy timeline

The above-mentioned policy instruments all span over different time intervals. Some of them, however, have well-defined deadlines on when to be achieved whereas the timeline in Figure 3 gives an overview of important years until the EU target of climate neutrality by 2050.

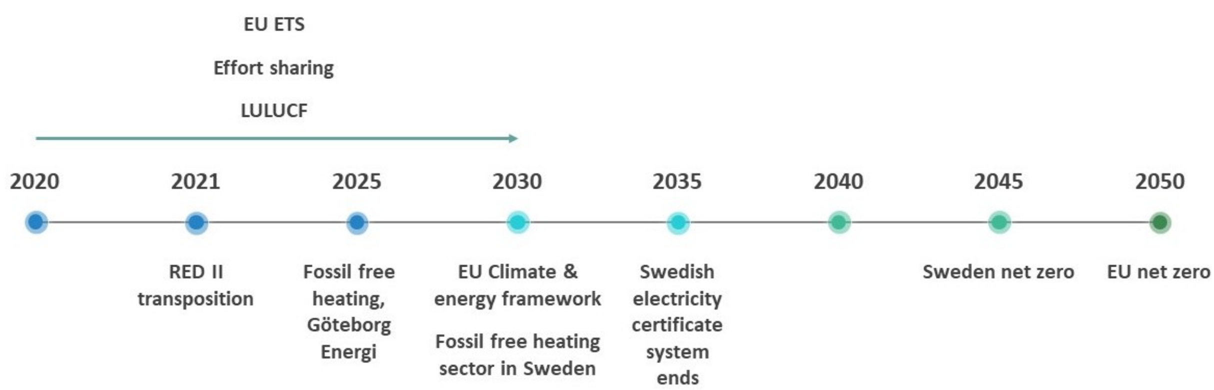

Figure 3: *Timeline of when current policy instruments end.*

As a last comment on the entire policy landscape, there will likely be many, diverse, temporary policy instruments over the years to come facilitating the transitioning which will continuously be phased out and replaced with new ones, as lifted by one of the interviewees.

4.3 Bioenergy feedstock options

Based on the results from the interviews, five main categories of bioenergy options are identified as interesting for further investigation; industrial byproducts from forestry and construction, forest residuals, domestic and industrial waste, agricultural residues and lastly various organic waste flows suitable for biogas production. The common denominator for all is making use of residues and waste, and aiming towards a more circular economy. Table 8 exemplifies what each category can include, after which potentials and predictions of each are presented.

Table 8: *Examples of bioenergy feedstock options included in each general category.*

Bioenergy category	Examples of sources
Industrial byproducts from forestry and construction	Bark Wood chips Sawdust Recycled wood and paper
Forest residuals	Tops and branches Rotten or sprinted trunks Stumps
Domestic and industrial waste	National International
Agricultural residues	Food crop residues Process residues from food industry Biofuel and biochemical production residues
Various organic waste flows suitable for biogas production	Organic waste Sewage sludge Manure Algae

4.3.1 Industrial byproducts from forestry and construction

Industrial byproducts from forestry and construction will continue to provide a stable supply to the energy sector. If, or likely when, the construction sector increases its use of biomass as raw material, its generation of byproducts and residues will also increase. In the fossil free transition, the dependence on raw material derived from fossil dependent industries such as cement, concrete and steel will have to decrease, why biomass raw material should increase. The generated byproducts and residues could end up as solid bioenergy fuels for the energy sector with likely insignificant competition from other sectors, such as wood chips, recycled wood, sawdust or bark. This is thus a promising potential fuel resource.

4.3.2 Forest residuals

As mentioned in Section 2.1.1 and as promoted by some interviewees, there is potential to utilise more forest residuals. However, there is currently no incentive for a private forest-owner to withdraw any residues, especially considering that it is not suitable for higher-value products thus not generating enough profit to cover for the effort and cost. In addition, many forest owners do not live adjacent to their forest nor have the forest as their main source of income[45]. It is thus doubtful the energy sector alone will muster sufficient willingness to pay to motivate these small-scale owners to withdraw residuals. Company- and state-owned forests on the other hand might offer more increase in residual withdrawal, but again this will depend on how profitable they deem it to be. Forest residual withdrawal could be promoted either if the Government decided to subsidise it or if other industrial sectors take a high enough interest in it. In either case if forest residual withdrawal is increased, there also needs to be a system for ash return. It seems unlikely the Government would decide to subsidise forestry residual withdrawal both considering nature conservation and habitat protection and as it would require a complex, expensive system. As for other industrial sectors, it is possible they could provide a high enough price to motivate forest residual withdrawal, and in this case it could increase. This could entail projects similar to GoBiGas where the main product is biogas that could be used for transport or in industrial processes. In this case, there would likely be solid residues from the gasification process which could be used as bioenergy, even if the energy sector is not the main cause of forest residual withdrawal.

4.3.3 Domestic and industrial waste

Waste CHP plants will continue to provide a stable source for DH in Sweden. The national supply of waste will not disappear even if it hopefully decreases in the years to come, both due to increased recycling and to decreased waste generation. In either case, there will still be hazardous industrial waste or end-of-life waste that can no longer be recycled that needs to be treated which is where waste incineration comes into play.

Considering Sweden's large heat demand and functioning infrastructure of DH, it would make sense to import more international waste, especially from countries with small to no heat demand currently relying on landfills. This would promote circularity and could be sold as a deconstruction service to other European countries. However, as some actors mentioned, there is opposition of both waste incineration in itself and of importing/exporting waste. Depending on how this debate develops, it could become either easier or more difficult for Sweden to increase its import of waste. One of the main concerns of waste incineration is its fossil content, which was also the reason for the implementation of the recent tax. It is unlikely the fossil content will cease to be a concern, why it needs to be treated. An opportunity for this could arise if, or likely when, chemical process industries and refineries start utilising and/or increasing recycled plastics as raw material. If they do, they will likely ensure sufficient willingness to pay to motivate extra sorting of imported international domestic waste, thus treating the issue of fossil content in waste incineration. As a result, collaborating with the chemical industry could prove to be a winning concept for waste incineration plants. From a local perspective, Sweden's only oil-cracker plant is located not far from Gothenburg and has an ongoing investigation of a net zero production, why this could be an interesting collaboration option for the fossil content of waste.

4.3.4 Agricultural residues

The Swedish national food supply is likely to increase due to higher consumer demand, possibly accelerated by the COVID-19 pandemic. Increased food cultivation and production inevitably generates residues, both directly from the inedible parts of the crops and indirectly from processing and refining. The residues from both are likely solid and possible to compress or dry to remove possible moisture

[45] In 2013, 25% of the private forest owners did not live adjacent to their forest [17].

[45] In Stenungsund, some 50 km north of Gothenburg, Sweden's only cracker plant is located, owned by Borealis [209]. It is part of the industry collaboration of sustainable chemistry by 2030 [184].

content. It is also possible some of the residues and byproducts is turned into animal feed. If, or likely when, the transport sector, notably heavy transport, largely increases its demand for biofuels the generation of residues that could be used in the energy sector increases. As before, these residues are also likely solid with some extent of moisture, but there could also be residues that can be gasified to biogas.

As some actors mentioned, Sweden has fallow land that could be used either to increase food production or, as a couple would prefer, to grow dedicated energy crops. As the study is limited to Sweden, the agricultural biomass will most likely mainly come from residues or energy forests even if dedicated energy crops might still account for a smaller share. One actor noted there is potential also in other European countries to increase crop production on fallow or under-utilised agricultural land. Depending on the implementation of RED II and to which extent the EU allows food-based energy crops this could increase but as mentioned this is very uncertain. It is also uncertain to what extent the implementation will impact the use of food crop residues. If the EU allows food-based energy crops, they are unlikely to be destined directly to the energy sector in Sweden. In that case, oil crops are likely cultivated which will go through several steps of biorefinery before ending up as solid bioenergy or biogas that the energy sector could utilise. If on the other hand the EU does not allow food-based energy crops, woody crops and energy forest could possibly increase more in Sweden, in which case the energy sector could likely receive a larger share of the biomass cultivated. In either case, the agricultural sector could likely provide the energy sector with fuel supply in the form of mainly solid bioenergy and to some extent even biogas.

4.3.5 Various organic waste flows suitable for biogas production

Organic waste and sewage sludge will continue to provide biogas that could be used by the energy sector. However, there might be competition from process industries of the biogas, in which case the latter likely amasses higher willingness to pay. This biogas is then likely better suited for peak production rather than base load.

Biogas production from manure requires equipment investments that are often too expensive for small scale farmers. Here resides an untapped potential biogas resource, where energy companies could provide collaboration opportunity or investment support to farmers in exchange for a predetermined share of the produced biogas for a defined period of time. In many cases, the farmer might not be interested in the biogas for their own use at all, in which case the energy company could access all biogas. Offering collaboration and support for investments also ensures no other sector can compete for this specific biogas resource. It would also be beneficial to the farmers as they can market the collaboration of providing biogas as climate positive and state that their manure imposes no methane emissions. Preferably, several farms should unite in one larger manure gas plant. This is being done in Kalmar, with the More Biogas Småland AB established in 2011[46]. Göteborg Energi has led an on-farm biogas project in Falköping that was in operation between 2011 and 2014 but was closed down due to lack of profitability and was dismantled in 2019 [212].

From a local perspective, there is large manure potential as the county of Västra Götaland has close to

[46] More Biogas Småland AB was established in 2011 as an answer to a group of farmers wanting to produce biogas from their manure already in 2007, however, the profitability of each having their own biogas plant was too low. It is today owned by 29 part-owners, including 18 farmers and the local energy company Kalmar Energi. More Biogas has a biogas co-digester (samrötningsanläggning) that converts manure from the farmers and food waste from nearby municipalities to biogas for transportation and biofertiliser that can be returned to the farmers [210, 211].

the highest amount of both cows and horses in Sweden[47], meaning local manure is not a scarcity. In addition, horse farms tend to be located closer to denser populated urban areas[48].

Biogas production from algae is not on commercial-scale but still under development. When it enters the market it will likely aim for higher-grade products, but could still generate residues useful for the energy sector. The residues would likely consist of solid algae paste or mush that could be compressed or dried to solid bioenergy fuel. It is doubtful this will expand at a sufficient rate to act as a fuel supply for the energy sector in the near future.

[47] In 2018, Västra Götaland had the highest amount of dairy cattle in Sweden with more than 60 000 milking cows. Including also heifers, bulls and non-dairy cows, the amount of cattle lands on approximately 185 000 [213]. For horse, Västra Götaland had second-most after Skåne in 2016 with more than 55 000 horses [214].

[48] In 2016, more than 70% of all horses and horse farms were located in or close to denser populated urban areas [214].

5 Discussion

The discussion is divided into five main parts, starting with future prospects of policy instruments, thoughts on the fossil free transition and the role of bioenergy in the future energy system. Thereafter follows a part on interpretation of interview findings and the section is concluded with suggestions on further research. Recall the research questions from Section 1.3, upon which the discussion is based:

1. What is the current situation, and tendencies for future development, concerning bioenergy related policy instruments in Sweden and the EU?
2. What challenges and possibilities are there in the fossil free transition?
3. Which bioenergy feedstock options are the most interesting for further investigation?

5.1 Future prospects of policy instruments

The first part of the first research question, concerning the current situation of policy instruments, is treated in Section 4.2, along with some predictions of development. From the interviews, it is clear RED II is the most prominent instrument and something where several see uncertainties. As mentioned in Section 4.1.1, the concept of uncertain politics was the answer of close to half of the interviewees to what they think is hard to predict or understand. The uncertainty covers several aspects, mainly changing regulations affecting the market environment and wavering views on sustainable biomass and its implication for usage of bioenergy and biofuels. There is consensus on policy instruments playing a key role in the bioenergy transition away from fossil resources and there is also consensus that clarity, distinctions and long-term perspectives are required to achieve this. For development to thrive, stable market conditions are desired where the risk of investment is minimised. Some suggestions of policy instruments to stabilise the market conditions to stimulate bioenergy development have surfaced during the interviews. One lifts bans on bad goods as forcing a fast technical development, which would indeed be efficient in urgent times as these. Some others suggest a quota system in one way or another, which could diminish investment risks while still reaching the desired environmental outcomes such as reduced emissions.

Policy instruments are needed not only to promote bioenergy development but also to enable the fossil free transition in itself. Several interviewees mentioned soft policy instruments targeting consumption patterns and facilitating collaboration between actors. The transition requires a shift in society, why these kinds of instruments would be highly beneficial. However, it is very complex for policy-makers to create these kinds of instruments. Soft values are highly dependent on the views of the onlooker, why there will always be opposition to instruments regulating consumption. Moving to other suggestions of policy instruments, one of the interviewees expressed an idea to implement an exponential tax on airplane tickets, as presented in Section 4.1.1. A policy instruments like this that targets over-consumption while still allowing one-off events to approximately the same cost as before, could be easier to implement and face less opposition.

So what would be the ideal environmental policy instrument? The short answer is that it depends on each location's specific circumstances, however several interviewees accentuate the need for common rules. Polluting has to be costly everywhere to ensure polluting industries do not simply relocate. Additionally, the polluter should pay and be held accountable for what they put on the market. Whether or not politicians worldwide will unite in combating climate change with common agreements and equivalent regulations on polluting operations, is ambiguous. Top meetings are being held and politicians promise grand transformations, while simultaneously, business continues as usual. Several interviewees conveyed a need for politicians to take responsibility, determine the game field and start acting. In different ways, they expressed the time for small contributions is over and now comes the time for giant leaps. The interviewees convey the issue of climate change can no longer be left untouched, there needs to be scientific-based interventions from governing regulations. But as one interviewee noted, the political processes are slow, and must to some extent continue to be in order to ensure democratic processes. However, politicians need to be brave and speed up the implementation of regulations helping to mitigate climate change instead of getting stuck on making small changes to the regulatory framework that only contribute slightly to enhance the green development but that are easier to get support for. With political governance being highly complex with many aspects to consider and decide upon, the climate is not always a top priority. Therefore companies could and should take the lead in combating climate change by investing in development of technology, bioenergy and other renewable sources as well as collaborating between sectors and countries to minimise investment risks and creating stable market conditions. Voluntary sector agreements like the Roadmaps are excellent examples that should be expanded to allow industry to pave the way. The transition to a fossil free society can and must come from within.

5.2 Fossil free transition

Both the literature and the interviewees suggest that the fossil free transition is crucial to reach the climate goals but that it also entails a number of uncertainties. In an attempt on answering the broad second research questions, several challenges and possibilities are discussed.
A first aspect is that money drives the transition, for better or for worse. Some industries and companies are ahead of policy-makers in doing the transition without "needing" it in order to gain market advantages, which is expressed in the different roadmaps. The fossil industry on the other hand performs strong lobbying to guard their interests and to stay on the market. The transition to renewable energy and products needs technology development and investments, which can be supported by policy instruments but some interviewees believe that it needs to come from market demand to be profitable in the long run. Nevertheless, stable market conditions and long-term political decisions are necessary to obtain a market that demands new technology and where companies dare to invest. The interviewees all agree technology will play an essential role but there are diverging opinions on the extent to which technology will contribute to the transition. Some firmly believe technology can and will tackle climate change but a couple of environmental actors express a fear of over-relying on future technology to the extent of not dealing with the issues here and now. Both sides hold valid arguments and to achieve a rapid transition, these arguments complement each other. The urge to act now and not procrastinate climate action combined with a belief in and development of technology is essential. However, technology is not a magic wand that solve all problems instantly and development will always come with trial and error. Furthermore, there is the societal aspect of acceptance of and adaptation to new technology. It is clear that if there are diverging opinions in our narrow group of interviewees, the opinions are even more diverge in society, why information campaigns are of great importance.

As Sweden aims to become the world's first fossil free welfare country, competitiveness is crucial to make others want to follow. The interviewees agree Sweden can act as a role model but that the solutions adapted to the Swedish situation cannot be copied straight off by other countries. Sweden can show that the transition is possible and that companies can benefit from taking an active part of it and not just waiting for policy makers to act. However, many interviewees underline that Swedish competitiveness must be maintained and that a market-driven transition will be more secure for the companies than national supports and incentives that might not result in international competitiveness.

Continuing with the market's role in the transition, consumption is important in the society we live in since consumption is what makes companies earn their money. Even though the interviewees in different ways promote circular economy with reduced energy and material consumption, there will still be companies wanting to sell their products in bulk. This reduces the incentives of creating a product that lasts forever since it will not generate as much income. Furthermore, the norm in Western culture is to never settle and constantly pursue more to be seen as a successful person. Therefore, consumption is often seen as an indicator of success, whether it is expensive cars, frequent holiday trips or champagne. The COVID-19 pandemic has shown that an abrupt decrease in consumption has a substantial impact on society, such as financial depression and increased unemployment. As a consequence, COVID-19 might act as an awakening call for the many to realise that the normal ways of our society is not sustainable.

Even though a large share of global emissions comes from industry and they need to step up their GHG emissions reduction game, people still play an important role in the transition. By being a consumer who asks for sustainable products and services, demand for this arises on the market which will have a direct impact on what is available, even though some people feel like their individual actions do not matter. However, it is hard to live a fossil free life in a fossil dependent world, as one of the interviewees stated. Therefore, the consumer can put pressure on companies to quicken the transition and as a result, companies understanding the market benefits in making a green transition will prosper whereas the ones clinging to fossil resources will perish sooner or later. Certifications play an important role since they are a means for companies to show that they live up to certain standards, facilitating for the consumers to make a sustainable choice. The interviewees also state a need for information and education to increase the willingness to change by enhanced understanding of climate change and the consequences of continuing with status quo. However, the environmental actors are more prone to believe that people will actually change their behaviour than the rest of the actors. Having the cake and eating it applies here, where people want a better climate but are not willing to adapt and contribute why it is crucial companies take the lead to facilitate a fossil free life for everyone. On the other hand, there is a risk connected with small actions to mitigate climate change, such as recycling or stopping to use plastic straw or disposables. It is the feeling of "I have done enough" that might create the illusion of living an environmental friendly life while still flying to Thailand on vacation. It is important to acknowledge and encourage every single step, no matter how small, but it is even more important to keep searching for the next step and not settle in the feeling of having done enough.

As previously mentioned, more than 4 Earths would be required if everyone lived as in Sweden but the accounting of emissions is always a difficult task, especially concerning import and aviation. That is the reason the polluter pays principle is important, together with a holistic view and sufficient system borders. People tend to prefer quick fixes that do not require as much an effort from them, but climate change does not have any silver bullet solution or quick fixes since it is too complex. All ecosystems are interconnected, resulting in the whac-a-mole effect lifted by one interviewee, why it is essential to keep multiple aspects in mind when dealing with these questions. Therefore, collaboration is necessary between all involved actors to cover as many aspects as possible.

The COVID-19 pandemic has shown the world that it is possible to make drastic changes but the climate has not gained as much credibility worldwide. Climate change is not as imminent as a virus that might kill you tomorrow, at least not in the mind of people. People are afraid of change and fear to lose the life they are living. The five stages of grief suggested by Kübler-Ross [215] can be applied to climate change as well since it is the loss of the world we are used to. First comes denial, the refusal of accepting climate change. This is followed by anger and then bargaining, where we identify opinions such as "technology will solve all problems so I can continue living my life" and "I recycle so I can fly to Mallorca". The fourth step is depression accompanied by a sense of hopelessness and the final step is acceptance, where you have accepted that climate change is real and needs to be dealt with. To reach acceptance, the aspects of information and education lifted by many interviewees are crucial.

A final aspect of the fossil free transition is that the discussion more often concerns measures to do in the future to mitigate climate change than what to do immediately. The goal of staying below 2°C remains even though every day of business as usual reduces the probability of reaching it. Nevertheless, there is a determination to succeed and many believe that technology development and future measures will save us but action needs to happen today, not tomorrow. The big question is how far down the line we will let society go before we accept that tipping points are passed and that mitigation measures will not be enough. When will we stop trying to preserve things that are beyond preservation and accept that we instead need to adapt to the new climate we live in? Maybe we need that small climate catastrophe mentioned by one bioenergy provider to muster climate action from all parts of the world since wildfires, species extinction and melting glaciers do not seem to be enough.

5.3 Role of bioenergy in the future energy system

As mentioned in Section 4.1.4, there is a consensus on bioenergy playing a substantial role in the future energy system. When discussing the subject, there are aspects relating directly to the energy sector in the form of bioenergy feedstock options but also aspects of future potential of biomass and of circular economies with extensive recycling.

Starting with the bioenergy feedstock options, most interviewees promote utilising residues for bioenergy and together with the categories identified in Section 4.3, it is deemed solid bioenergy options have larger potential than liquid or gaseous ones since most categories could likely provide some form of solid bioenergy. Liquid bioenergy options, such as biooils and biodiesel, were deselected already in the limitation of the thesis, as it is deemed the transport sector will muster a much higher willingness to pay for these. Similarly, gaseous bioenergy options, namely biogas, are likely to also be wanted by other, higher-paying sectors. Here, chemical and other process industries compete of the resources in addition to the transport sector. Returning to the possibilities of increasing solid bioenergy, there is a challenge concerning the moisture content as this impacts the choice of furnace. The furnace type and its investment cost as well as the fuel handling and its heating capacity depends on the moisture content, which poses an issue as one and the same furnace can seldomly handle a variety of fuels and moisture content. However, most of the solid bioenergy options could likely be dried or compressed to form pellets of a more consistent quality facilitating the furnace choice, but on the other hand energy is required to make the pellets. Moreover, even though solid bioenergy options will likely provide the largest amount of bioenergy, it still holds certain limitations when it comes to the fast ramp-up times needed for peak production given the current infrastructure. Thus, for peak production, biogas would be desirable. To obtain a secure supply of biogas to the energy sector we would like to emphasise the possibility to collaborate with farmers on building biogas plants, as presented in Section 4.3.5. Even though Göteborg Energi's previous attempt on this in Falköping proved unfruitful, the times are changing and what was unprofitable in 2014 might be profitable today, as seen with the case of the Kalmar facility.

In a Swedish perspective, bioenergy production generates employment locally and could promote national self-sufficiency. All parts of the value chain for bioenergy will generate work opportunities, from farm-level cultivation and forest management to processing, refining and production, to marketing and sales. An increased national supply and production of bioenergy, biofuels and other biomass-derived products also preserves local employment in industry, product development and research. Bioenergy feedstock options from various byproducts and residues are not deemed to be scarce in Sweden, however it is important to note that it is dependant on continuous production from other parts. Even if Sweden would become self-sufficient on biomass-derived products, it will likely not be self-sufficient for all components in all industries. If production for some reason stops, it inevitably also stops the residue flow. As seen with COVID-19, a total industrial stop can pose a real threat to society, but it does not have to be as catastrophic as a pandemic. A stopped residue flow could be induced by trade-barriers creating lack of certain components stopping production.

Another important aspect to note is that even if Sweden could make do on only residues for bioenergy, this will not be the case worldwide. To supply the global energy demand without fossil components, either the energy demand will have to drastically decrease or the amount of energy from renewable energy sources will have to drastically increase, including bioenergy and biofuels, where the latter probably seems more appealing. In a future world with fossil free energy production, bioenergy from residues will not be enough. Dedicated energy crops will be required, either oil crops for biofuels or woody crops for heat and electricity. The bioenergy feedstock options identified in Section 4.3 are thus impacted by the thesis limitation to Sweden, and would likely look different if a global perspective would have been adopted.

Remaining on the dedicated biomass production, one interviewee accentuated an abundant potential of biomass resources both in Sweden and worldwide. However, as another interviewee stated, bioenergy is only renewable when cultivated in a sustainable manner. This leads into the discussion of whether or not biomass should be considered carbon neutral. As mentioned, the boundaries and timescale used highly impact the assessment, likewise if one small grove is regarded or an entire forest. The question is complex, but as the interviewees stated, if managed in a responsible, sustainable manner both forests and agriculture can be considered carbon neutral. In Sweden, we often pride ourselves with our sustainable forest management and its multiple climate and environmental benefits, but as some interviewees noted, it could also be viewed as enormous monoplantations. From a legislative perspective, bioenergy is considered carbon neutral and exempt from Swedish CO_2 and energy taxes.

Continuing on the view of bioenergy leads us into the debate of production versus protection which is stated by many interviewees to be highly prevalent in EU policy discussion, especially concerning forestry. The Swedish forest differs from forests on continental Europe by both being substantially larger and having a long tradition of forest management, as mentioned in Section 2.4.2. However, it is not only local conditions that affect the view on biomass production but also which environmental issues are chosen for consideration and emphasised. There is the question of forests' role as carbon sink, where some advocate for leaving the forests be and others for sustainable management, including some production, that helps binding more carbon. Biodiversity is another prominent question, with forests providing habitats for many species. Amongst our interviewees, both the production and protection sides were defended and they provided arguments promoting their points of view which are all valid based on their assumptions and boundaries. Some also stressed how ridiculous the other side's arguments are, further promoting their own view. Other interviewees focused on how to find common grounds and compromises between these conflicting opinions. This gives a taste of the real polarisation on the issue, and as many interviewees discussed, the complexity of the question demands for a holistic approach that considers all environmental aspects to find solutions that cover them all. Depending on policy development, either of these sides could get legislative ground for their arguments, reducing the debate. There is a possibility the implementation of RED II, the new

Biodiversity strategy and the EU Green Deal could lead to new rules concerning sustainable biomass production.

An aspect that has not been considered in this thesis, is the impact climate change will have on the forest growth rate. The warming will inevitably change the conditions for both agriculture and forestry in Sweden and other northern nations as well as in the rest of the world. A warmer climate in the northern countries implies longer growth seasons but also more infestations. The further north, the higher the warming is expected to be, i.e. higher than the global average. This means the boreal forest will suffer extra warming and even face extensive forest death if the warming reaches 3-5°C [21], which unfortunately does not seem too far off based on the current business as usual. The issue of preservation versus adaptation re-emerges. In a drastically changing climate, fauna and flora will inevitably suffer and biodiversity faces major threats. Urgent calls for preservation in a desperate attempt to decrease the rate of the ongoing species mass extinction are prevalent in today's society. But will the calls be heard? Will there be enough action to save the melting glaciers or the dying coral reefs? How far will we push the preservation, how much will we try to recreate? Nature has the ability to evolve and adapt to new a climate, however it takes time for these changes to enter into force and inevitably not all species will survive the changes. Society needs to provide conditions, and especially time, for nature to adapt by slowing down and mitigating climate change. How long will we cling to the idea of preserving a landscape that is already lost? Will it be for so long that we miss our chances of adaptation?

Another biodiversity issue is the rainforest deforestation to make space for enormous monoculture crop plantations, which often receives media attention, especially in the case of Brazil. The flourishing habitats and countless biodiversity as well as the rainforests' importance as the Earth's lungs are often highlighted, and the continuous disappearance is problematised and concerns many. So, who decides which forests should receive protection and which should be cultivated? Does the fact that Sweden has historically exploited our forest, placing our carbon depth centuries ago, give us permission to continue cultivating forest? Why should other forest-dense nations not be allowed to cultivate theirs, simply because they have not done so historically? It is easy to dismiss the comparison of Swedish forests with tropical rainforests by pointing to the fact that they are very different after all. However, the same can not be said for the old natural forest in Russia, as this is a boreal forest, same as the one in Sweden. Let us travel this train of thought. Almost 40% of the world's forests are boreal forest, and half of this resides in Russia [21]. Needless to say, this could account for a huge potential of biomass resource. However, with climate change and some degrees of warming, not only the forest in Russia would be damaged, but also the tundra could be impacted. When the land becomes warmer, it will start to release its large methane reserves, currently held in place by the permafrost. An argument made to keep the Russian forest intact is both its age, biodiversity and role as carbon sink. But if the forest due to the warming anyways faces extinction, turns the carbon sink to a carbon source in addition to the massive carbon release from the surrounding land, would it not be better to utilise the biomass potential in an attempt to mitigate climate change, at least a little? To help end the fossil dependence? Cultivating the immense Russian forest would undeniably generate an enormous carbon debt at the start, but could this not be defended by substitutional effects of biomass products and the fact that a cultivated forest will be protected by its owners from infestations caused by a changing climate? If Russia could make money off forest management and biomass export, would they abandon their current exploitation and export of fossil natural gas? Could market profitability of biomass-derived products end their fossil use? Sweden once started extensive forest management generating an enormous carbon debt, only this was some two hundred years ago. The overall opinion is that the management of Swedish forests should keep going since the damage is already done, deeming it would be a waste to not utilise it now that we have it and when the world is in desperate need of fossil free alternatives. In a perspective were all countries have a moral right to take the same development paths, Russia should be allowed to manage their boreal forest similar to how Sweden has historically done. However, the large initial carbon depth this would cause would happen in a world were this could be the tipping point pulling the climate crisis over the edge, causing irreversible effects. When Sweden started its forest management, the world was still blissfully unaware of the consequences the massive carbon releases would cause in the future. Back then, no one knew. The same can not be said today. Today we know the world is standing on the verge of irreversible damage. Here, a parallel to the industrial and developing nations can be made. In a moral perspective, developing countries should be allowed to make the same journey to welfare as the industrialised world has done. However from a climate perspective, it is crucial they do not follow the same paths of industrialisation, as we now know this has polluted and damaged the world. Instead, they can profit from lessons learned by industrialised countries and jump straight into more sustainable solutions. As it is not possible to share opportunities equally between countries, nations like Sweden that took these opportunities historically have to make a bigger effort and take more responsibility today. This includes helping developing nations turn industrialised while minimising harm to the climate or environment, by sharing resources and technical solutions. Based on this, Sweden's goal of becoming the world's first fossil free welfare nation is not just a goal, it is a necessity and a moral responsibility.

Returning to bioenergy in the Swedish energy system, CHP and DH continues to be important by providing a reliable, steerable energy source, suitable for base load production, as lifted by several interviewees. Even in a system with other renewable energy sources, these are important aspects, why we also believe CHP will remain in the energy mix. However, it is important to note that bioenergy is not the sole solution. Other renewables, such as wind, solar and geothermal power, should be investigated further and expanded side by side with bioenergy use. The energy mix of the future would thrive of divers, various contributions. Note that the thesis has not taken into consideration how climate change will impact the future heat, cooling and electricity demand and how a drastic change in demand would impact the current energy system. The demand is assumed to follow predicted trendlines.

In a Swedish energy system similar to the one in place today, another bioenergy option suitable for CHP plants where we see large potential is imported waste. Given potentially stricter regulations on certified sustainable biomass derived from RED II, it is possible the export of Swedish biomass to other European countries will increase as it already has some sustainability certifications. This could imply the biomass available for bioenergy in Sweden might decrease, however this could then be compensated by increased import of waste for incineration. Several European countries, not to mention other countries of the world, still rely to a large extent on landfill. If Sweden could market waste incineration as a destruction service enabling circularity, as suggested by one of the interviewees, the opposition might be persuaded. One interviewee noted the Swedish model would not work if everyone did like Sweden while another conveyed Sweden treating other countries' waste could be seen as a sort of producer responsibility, considering the amount of exported goods from Sweden. Waste incineration is perhaps not the answer to making the future energy system fossil free, but while the system expands and adapts renewable energy sources continues, waste incineration can kill two birds with one stone in the meantime by providing heat and electricity as well as promoting circularity and reducing landfill. By contrast, one major issue of waste incineration remains, its fossil content. In addition, imported waste has an even larger fossil share than domestic. To solve this problem, we propose collaboration with chemical refineries, as presented in Section 4.3. Today these industries are heavily reliant on fossil oil as raw material, but in the coming decades they too need to become if not fossil free then at least net zero emissions. For these industries, the fossil share of imported waste could be the solution and they would likely be willing to pay enough to sort the waste once it has come to Sweden to cover the costs of either investment in mechanical sorting or salaries for people to manually sort. For a waste incineration plant this could prove highly profitable, as first the exporting country will pay for the treatment of its waste, then the chemical industry will pay for the fossil share and lastly, consumers will pay for the recovered energy. However there is one prominent challenge concerning increasing the import of waste, which is the political resistance and view on this import in itself. There is political resistance towards waste incineration in itself as seen with the tax on waste incineration, which was implemented regardless of several instances disagreeing with it. As highlighted by a couple of interviewees, there is both political and societal resistance of both waste export/import and incineration. Due to this, it is not sure whether or not is it possible to increase the waste import. On the other hand, the major issue causing the resistance is the fossil content in imported waste and if it is made clear the fossil content will be recycled and replacing virgin fossil raw material the resistance might be persuaded. It should be attractive for Swedish politicians to replace fossil raw material as this will help achieve the goal of being the worlds first fossil free welfare nation.

Several interviewees promoted a society with a circular bioeconomy, reuse and recycling. Increased efficiency in the use of raw materials and energy sources leads to reduced pressure on the environment providing these sources as well as reducing the amount of waste. To achieve the sustainable future everyone is longing for, increased circularity and efficient resource use will be necessary in all parts of society. For a long time, success have been equal to increased consumption and increased material possession. Today, society is redefining the notion of success and it is à la mode to live a more sustainable life, reducing one's environmental impact in whatever small ways possible. This is reflected in words like staycation, the Swedish word flygskam (shame of flying) and the zero waste movement. Several interviewees raised the younger generation as being more environmentally conscious and driving this societal change.

However, the note from one of the interviewees of recycling being but a mere definition and only a question of cost and societal will, stuck. The follow-up question irrefutably arises: at what cost should everything be recycled? Several interviewees, especially energy actors and bioenergy providers, accentuate that bioenergy should come mainly from residues and that high-grade biomass should primarily be used for other purposes. However, something made from high-grade biomass is coffins, which more or less go directly to incineration, and far from always is the heat even recovered. This poses an interesting food for thought. Moreover, in Sweden all organic waste should be recycled, either by private composting or by municipal digestion or gasification. Where do we draw the line for organic waste? Should a pet be considered organic waste when it dies? Should grandma? The question of recycling everything quickly escalates and entails a heap-load ethical considerations.

Pushing the question of recycling even further while taking the waste hierarchy into account raises a new question: should waste be prevented from occurring in the first place? Implementing policy instruments that tackles over-consumption opens for the question of what counts as over-consumption. If it is unnecessary to fly far away on vacation by claiming it serves no purpose, is it not also unnecessary to breed animals for racing so that people can spend their money on bets? One could argue breeding animals could be defended with it serving the purpose of feeding people, but what is the purpose of keeping household pets? Would banning pets align with preventing waste as they consume additional food and products? Does China's one-child policy? Who is to decide what is allowed and who should be held accountable? Is a society with unconditional circularity where everything is recycled and all waste is prevented from occuring a desirable society? When heading towards a circular bioeconomy, it is important to allow time for pausing and reflection. We can and must move towards a circular bioeconomy, but we also have to ensure it remains sustainable and is not pushed too far in order to maintain a healthy environment. It is a balance between doing too little and doing too much that requires consideration of many aspects to cover for the complexity of the issue.

5.4 Interpretation of interview findings

It is important to discuss the interpretation of the interview findings, as they are a result of the questions asked and might be influenced by personal biases, whether conscious or subconscious. When it comes down to opinions and predictions, there are no right or wrong answers although some of the topics are emotionally charged, creating a perception of right and wrong. It is worth noting that the same facts can be modified to present contradicting facts confirming one's belief based on the chosen statistical presentation. Is bioenergy production preventing climate change or harming nature and endangering biodiversity? It all depends on the context, the framing and the assumptions made.

To start with, the interview questions are intended to be neutral and open-ended, but are still framed in a context that might influence how different people respond. As the questions varied somewhat both in order of appearance and sometimes formulation to relate to the specific interviewees and the flow of the interview, the actors might have perceived them differently. Moreover, the interviewees had different approaches to answering questions, some were very concise and answered only the question asked whereas others deviated and floated into other, somewhat related subjects. When choosing which responses to exemplify agreements with, we note that some actors use a more animated language with more metaphors, why these actors' responses are often highlighted. The fact that some interviewees are alone in expressing opinions on certain topics relate to some extent to how they answered questions, but also to them being more alone in their field of expertise. Thus, some opinions given by one or a few interviewees might be shared by others even if this has not showed in the interviews. On the other hand, not all opinions presented as consensuses are explicitly stated by all but is instead a perception on our part that there is. This leads to our interpretation of what the interviewees meant with their answers coming into play, both in how we have noted their answers and in how we chose to present them. Nonetheless, we believe we have done a good job in representing the answers, not least considering we have given all interviewees the possibility to proofread and offer alterations on the statements based on their answers, in case we originally misunderstood them.

How a question or response is framed and which definitions one chooses to base them upon also influences the obtained results. The framing of the interview questions is inevitably influenced by our perceptions of the topics, which might also create a confirmation-bias on our part. The questions were asked on policy instruments, fossil free transition and bioenergy options in Sweden, why a global perspective to some extent might be lacking, even if this was delimited in the scope. For the interviewee's part, the framing of and which facts highlighted influence their answers and how they come across. Likewise, their roles and underlying agendas and values influence their answers and opinions for and against certain things. It is interesting to reflect upon whether the actors profit from presenting certain opinions, if their company or organisation restricts their expressions and which facts they console and believe in.

Regardless of the actor category, many opinions do harmonise and most agree with each other on at least some topics. We note that a majority of the interviewees we have recuperated are more or less in the same field; many of them even know each other. Most of the interviewees were suggested by our examiner and/or supervisor, why also the selection process might be somewhat biased. On the other hand, some actors, exclusively academics and environmental actors, we found on our own accord. However, these actors responded to our request that included the scope of the project, meaning likely only those interested in the topics responded. In general, actors agree with other actors in the same category, especially the energy actors and bioenergy providers, which were to be expected. However, the environmental actors diverge somewhat to a larger extent than other categories, where we speculate there might be a difference between those whose environmentalism borders more to nature and those to climate. Those more prone to climate environmentalism tend to agree more with the other categories. In some areas, actors from different groups disagree and have completely opposite opinions on the matter, such as how forests should be managed and the view on increased outtake of forest residuals as well as what should be included in the polluter pays principle. They all provide arguments validating their standpoint and advocate for it being the right opinion to have.

5.5 Further research

With research questions concerning future tendencies and development, it is impossible to obtain findings that last over time. This thesis gives a snapshot on what our interviewees think will happen and they all express incertitude regarding the future. The political climate is ever-changing and technological breakthroughs might wait around the corner, affecting the role of bioenergy. For further investigation it would be interesting to broaden the perspective and include interviewees from the EU and other countries since these issues do not only concern Sweden. In the suites of the COVID-19 pandemic and all different rescue packages it would also be interesting to study how this impacts the environment and what changes will come on the other side of the pandemic. A further topic for investigation is possible parallels between actions concerning COVID-19 and the environment, and what lessons can be learned from the pandemic that can be applied to combat climate change.

Furthermore, conclusions from this thesis are based on the current energy system and it would be interesting to couple the composition of the future energy system with bioenergy development. Relevant aspects are changes in demand, technology development and how climate change might impact both the energy demand and the availability of biomass. The take on bioenergy as a means of mitigating climate change while global warming might result in increased forest growth rate is intriguing.

It would be interesting to perform further research on the identified categories of bioenergy feedstock options in order to assess which would be most interesting to invest in. A research of this could include aspects of availability, cost and relative carbon emissions. It would also be interesting to investigate bioenergy options in a global perspective. Another area of further investigation is dedicated biomass production systems and what impact they have on the surrounding ecosystems. A take on this is how these systems can be designed and managed to obtain positive effects on the surroundings, such as improving soil quality, land use and water productivity as well as promoting biodiversity.

For further research it could also be interesting to investigate how an implementation of the SDGs into national law would impact both the policy landscape and the development of bioenergy. This could include prospects of transposing the SDGs onto the existing Swedish environmental goals. Lastly, further research could be done on refining recycled plastics from waste to use as resource material in chemical industries.

6 Conclusion

Bringing this thesis work on policy instruments for bioenergy development to a close, the conclusions made are separated to answer the three research questions and lastly key insights of the whole report are listed.

6.1 Research questions

What is the current situation, and tendencies for future development, concerning bioenergy related policy instruments in Sweden and the EU?

There is a broad spectrum of policy instruments concerning bioenergy, presented in 4.2. For the energy sector, the policy instrument most interesting for continued monitoring is the implementation of RED II and its implications on what is considered sustainable biomass. The other environmental policy instruments are not as unpredictable, but still holds some uncertainties of their own. Concerning both forestry and agricultural policies, carbon taxation and waste incineration, Swedish regulations will likely be the dominant ones.

There is consensus among the interviewees that policy instruments, the political situation and their developments are difficult to predict and entail a lot of complexity. All wish for clarity, distinctions and long-term perspectives in the policy instruments and many advocate for investment supports for the development of bioenergy or fossil free transitioning. Several acknowledge there is no optimal universal policy instrument and that it is important to take context and local conditions into consideration. In Sweden, a reversed auction scheme for CCS support is emerging whereas a support scheme for rewarding power capacity of CHP is not yet on the horizon.

What challenges and possibilities are there in the fossil free transition?

The interviewees agree the fossil free transition is crucial to combat climate change and the possibilities lie in increased awareness and a willingness to change. Companies precede policy-makers in transitioning to gain market advantages since they know that they will be outcompeted if they stick to a fossil agenda and as such, money drives the transition. Even though the market plays an important role, policies could still be needed to eliminate initial investment risks of new and necessary technology development. The fossil industry is currently fighting for its survival but will need to be phased out eventually. Energy efficiency and circular economy will be of great importance, reducing the need for virgin resources. This requires changes in attitude and mindset from society, both companies and citizens, whereas information and education are of utter importance. People need to understand why they need to change, and in order to get other countries on board, Sweden needs to show the world that it is possible to be a fossil free welfare nation. By sharing knowledge and technical solutions, Sweden can inspire and encourage others to make their own transition to become fossil free. BECCS is identified to contribute to net carbon removal and CCS can be of use in a transition period for industries struggling with being fossil free, however not as a reason to continue business as usual.

Which bioenergy feedstock options are the most interesting for further investigation?

As presented in Section 4.3 and discussed in 5.3, the most interesting bioenergy feedstock options are those made up by residues and/or byproducts from either of the following categories: industrial byproducts from forestry and construction, forest residuals, domestic and industrial waste, agricultural residues and lastly various organic waste flows suitable for biogas production. Most likely, these sectors can provide either solid bioenergy or biogas that could be used for energy purposes. If import/-export of waste continues to be allowed, there is also potential of increasing the waste incineration, especially if collaborating with chemical refineries on the fossil content and if importing more waste from countries with low to no heat demand. Depending on the outcome of RED II, energy crops and residues from food crops will have different potential as energy sources.

Related to bioenergy options is the strong polarisation between different parties on the views of forest management and sustainable biomass production and supply which hinders collaboration and common agreements. It is thus important to find common denominators, however small, upon which the parties can agree and build from there in order to reach a common goal and an acceptable solution. Here the interviewees see it is important to holistically consider bioenergy systems and optimise them based on local conditions.

6.2 Key insights

Lastly, the following list presents the key insights identified throughout the thesis work.

- There is great uncertainty concerning the future of policy instruments, which implies that there is no clear answer to what is best to invest in.
- The largest uncertainty is political uncertainty, which creates unstable market conditions meaning there are high risks for investors.
- Clarity, distinctions and long-term perspectives in policy instruments are identified as necessary to handle the uncertainty and the investment risks.
- Companies need to collaborate and find sustainable and profitable solutions even in the lack of political support.
- Policy instruments, bioenergy options and technical solutions need to be optimised based on local conditions.
- In Sweden, residues and waste are considered most interesting for bioenergy applications.
- The implementation of RED II in 2021 will likely affect what is considered sustainable biomass and it is therefore important to engage in the development related to RED II.

6.3 Final comment

To conclude this thesis on policy instruments for bioenergy development, there are a lot of measures already in place to facilitate the fossil free transition, and bioenergy will continue to play an important role. It is possible to expand the use of bioenergy, especially through increased use of residuals from forestry and agriculture, as long as this is done sustainably. Concerning future support and regulations, these are issues that come with uncertainty and need to be continuously monitored. It is not possible to give any concrete recommendations on how to proceed with the fossil free journey. Instead, as a final message of this thesis, we would like to cite Antoine de Saint Exupéry: "As for the future, your task is not to foresee it, but to enable it".

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Appendices

A Interview questions

The majority of the interviews were conducted in Swedish but the questions given below are translated into English. Note that the order varied between interviewees and that the questions where asked in somewhat different forms depending on the context of the ongoing interview. Hereafter follows firstly the base questions asked to all interviewees and thereafter the most frequently asked follow-up questions.

Base questions

- Who are you and what is your role [at X]?
- What challenges and possibilities do you see in the fossil free transition?
- What role do you think bioenergy will have in the future? Are there any more interesting options?
- Do you see any obstacles in developing/increasing bioenergy use?
- What tendencies for environmental policy instrument development do you see in Sweden and the EU?
- Do you see any political processes hindering or encouraging the development of policy instruments?
- What do you think about the future role of Sweden from a global perspective?
- Concerning everything we've talked about today, what do you think is hard to understand or predict?
- Is there anything else you would like to add that we haven't talked about?

Follow-up questions

- What is the current situation concerning bioenergy and related policy instruments?
- Which policy instruments would you like to see? Both Sweden, EU and maybe globally.
- What do you think of the future energy system? The role of CHP?
- What do you think of the future of CCS/BECCS?
- How do you perceive the societal opinion concerning this?
- What challenges and possibilities do you see in reaching the climate goals as well as other environmental goals, such as biodiversity?

B Interviewees

As mentioned in Section 3, the interviewees are categorised according to their role in four groups; energy actors, academy, bioenergy providers and environmental actors. The descriptions are gathered from their respective employment websites, linked-in or given by the person in question.

Energy actors

Svante Axelsson - *National Coordinator, Fossil Free Sweden (Fossilfritt Sverige)*
Svante Axelsson is National Coordinator for the initiative Fossilfritt Sverige where he acts as the link between the actors and the government to facilitate the fossil free transition. Further, he spreads the word on the possibilities with the transition and creates challenges for companies and sectors to quicken the development [7]. He describes himself as a dance teacher that makes the politicians and business take steps together and dance towards the common vision of a carbon neutral future [private communication]. Earlier on, he was Secretary-General at the Swedish Society for Nature Conservation (Naturskyddsföreningen) for 16 years. His academic background is from the Swedish University of Agricultural Sciences where he studied environmental economy and stayed five years afterwards as an adjunct lecturer [Linkedin].

Erik Dotzauer - *Energy Policy Expert, Stockholm Exergi*
Erik Dotzauer is Energy Policy Expert at Stockholm Exergi, where his work includes Public and Regulatory Affairs related to energy systems and district heating. Dotzauer has a Ph.D. in Optimization Theory and was during the period 2006-2018 employed as Adjunct Professor at Mälardalen University, where his research focused on energy systems modelling in co-operation with the Forestry Department at International Institute for Applied Systems Analysis (IIASA). Dotzauer is a member of the board of Swedish Bioenergy Association (Svebio) and of “Energiutvecklingsnämnden” (EUN) at Swedish Energy Agency [private communication].

Lars Holmquist - *Public Affairs, Göteborg Energi AB*
Lars Holmquist is responsible for Public Affairs at Göteborg Energi, where he has worked for over 20 years [Linkedin]. He started out with environmental issues but have over the years become more involved with policy instruments and strategic business development [private communication]. Holmquist’s academic background is from Chalmers University of Technology, where he has a master’s degree in Chemical Engineering. In addition he has studied environmental policy instruments, environmental management and human ecology [216].

Karin Jönsson - *Energy Policy Manager, E.ON Sverige AB*
Karin Jönsson is currently Energy Policy Manager at E.ON where she works with public affairs and public relations [Linkedin]. Jönsson has 15 years of experience in the energy industry where she’s worked with business development in electricity generation, wind power establishment and as strategy manager for Sweden at E.ON. Before this, Jönsson worked with environmental and energy issues in the construction industry. Her academic background is from the Faculty of Engineering, Lund University, where she has a technical licentiate Industrial Environmental Economics [private communication].

Raziyeh Khodayari - *Senior Advisor Environment, sustainability and Fuel Supply, Swedenergy (Energiföretagen Sverige)*
Raziyeh Khodayari is Senior Advisor Environment, sustainability and Fuel Supply at Swedenergy [217], which includes amongst other things issues concerning policy instruments, the entire value chain of bioenergy, energy production and district heating [private communication]. Khodayari has

more than 20 years of experience from the energy industry and was an advisory board member of the Swedish Energy Agency 2014-2016. Her academic background is in Chemical Engineering from Lund University, where she has a PhD within the area of flue gas cleaning. Khodayari has a broad knowledge on the combustion of biomass and waste at heat and power plants [Linkedin].

Karl Sandstedt - *Biomass Specialist, Göteborg Energi AB*
Karl Sandstedt is a Biomass Specialist at Göteborg Energi AB. His work ranges from operational sourcing of feedstock and contributing specialist skills in new projects to working with strategic issues in the field. This includes work in trade organisations to address current issues through the EU Clean Energy Package and RES Directive, which both have an impact on biomass to the energy sector. Sandstedt has a background in the forestry sector and he has worked to improve forest management efficiency. He was logistics manager at Sveaskog, the state-owned forest company, and he worked early in Swedish forestry to develop and implement company certification and environment management systems [private communication].

Jonas Torstensson - *Business Development Biomass, E.ON Sverige AB*
Jonas Torstensson works with Business Development Biomass at E.ON where his tasks include ensuring fuel supply to all E.ON's Swedish plants as well as issues regarding the entire supply chain, from market to politics to sustainability [private communication]. Torstensson has more than 25 years of experience in the energy industry [Linkedin] and is currently a deputy member of the Svebio board [218].

Bioenergy providers

Kjell Andersson - *Communications and policy director, Svebio*
Kjell Andersson is the Communications and policy director at Svebio where he has worked for the past 15 years. At Svebio, Andersson is the head of a working group for sustainability issues and he has connections to Bioenergy Europe. Further, he has been an integral part of the making of the roadmap for bioenergy. In his early career, Andersson was an economy journalist and has his academic background in history and arts [private communication]. In addition to his writings on the topic of bioenergy, He has co-written several books about genealogy [219].

Sofia Backéus - *Forest Management and Climate Expert, The Federation of Swedish Farmers, Forest owners division (Lantbrukarnas riksförbund (LRF) Skogsägarna)*
Sofia Backéus is Forest Management and Climate Expert at LRF Forest owners [220], where she among other things works with silviculture, climate and sustainability questions [private communication]. Backéus has previously worked at both the Swedish Energy Agency, Svebio and the Swedish Standard Institute. Her academic background is from the Swedish University of Agricultural Sciences where she has a PhD in Forestry and is Forester (Jägmästare). Her research included forest management considering climate change [Linkedin].

Magnus Berg - *Director Public Affairs, Swedish Forest Industries (Skogsindustrierna)*
Magnus Berg works as Director Public Affairs at Skogsindustrierna where he also promotes fossil freeness. He has been an integral part of creating the roadmap for the forestry sector [221]. His work at Skogsindustrierna includes the entire value chain from plant to product security issues. He also works with environmental politics and has connections to their office in Brussels [private communication]. Previously, Berg has been Member Manager at Södra 2002-2017 and was the Department Secretary of the Swedish Ministry of Enterprise and Innovation 2001-2002 [Linkedin].

Jens Berggren - *Sustainability Expert, The Federation of Swedish Farmers (LRF)*
Jens Berggren is Sustainability Expert at LRF where he works with the three aspects of sustainability, ecological, economical and social [private communication]. Prior to this, he worked for 10 years at Stockholm International Water Institute as director for first prizing and then communication. He has also worked at both the Swedish Ministry for Foreign Affairs (Utrikesdepartementet) and Sida with issues connected to water and climate change. He started his career as a trainee at Vattenfall after a master of Agronomy at the Swedish University of Agricultural Sciences [Linkedin].

Jenny Näslund - *Energy Policy Expert, The Federation of Swedish Farmers (LRF)*
Jenny Näslund recently started as Energy Policy Expert at the agricultural part of LRF [Linkedin]. Before this, she worked for 8 years at the Swedish Energy Agency as Programme Manager, where she among other things worked with sustainability criteria, biofuels and the Swedish electricity certificate system. Näslund's academic background is from Södertörn University in Administrative Law and European Studies [private communication].

Klas Svensson - *Technical Advisor Waste to Energy, Swedish Waste Management Association (Avfall Sverige)*
Klas Svensson is Technical Advisor Waste to Energy at Avfall Sverige [222] where he coordinates development projects and represents the waste industry towards politicians [private communication]. At Avfall Sverige, he has previously been advisor on biological recycling and landfill. Before that, he has worked with supervision and probation of hazardous activities such as incineration plants and landfills. He has a master of science in ecosystem technology from the Faculty of Engineering at Lund University [Linkedin].

Göran Örlander
Chief Forester, Södra Forestry (Södra Skogsägarna)
Göran Örlander is Chief Forester at Södra where he's worked for 17 years. His tasks include forestry related research and sustainability issues as well as some commercial and industrial policy issues [private communication]. Since 2016, Örlander is the president of Skogforsk, the research body for Swedish forestry sector [223]. He is also member of the Royal Swedish Academy of Agriculture and Forestry (Kungliga Skogs- och Lantbruksakademien, KSLA) where he's previously been the president [private communication]. In addition, he received KSLAs gold medal this spring for amongst other things his contributions to developing Swedish forestry research [224]. Örlander's academic background is from the Swedish Royal College of Forestry where he studied forestry and silviculture to become Forester (Jägmästare), followed by a PhD in Forestry from the Swedish University of Agricultural Sciences [Linkedin].

Academics

Pål Börjesson - *Professor in Environmental and Energy systems, Lund University*
Pål Börjesson is professor of Environmental and Energy Systems Studies and has a background in agricultural and forestry sciences. Börjesson has 25 years of experience in the field of multi-disciplinary systems studies of biomass-based energy and production systems and his research focus on sustainability performance of existing and emerging biomass-based systems from a life cycle perspective, including environmental, carbon footprint, resource and energy efficiency, and cost performance. His research also includes biomass potential assessments and policy studies [225].

Hans Hellsmark - *Associate Professor in Innovation and Transition studies, Technology Management and Economics, Chalmers Univesity of Technology*

Hans Hellsmark is an associate professor at Technology Management and Economics at Chalmers and coordinator of Chalmers Initiative for Innovation and Sustainability Transitions. In Chalmers Energy Area of Advance, he is one of the profile managers for the profile area Technology Governance in Energy Transitions and he is also Chalmers coordinator for the Swedish knowledge center for renewable transportation fuels. His research focuses on innovation policies for transformative change and especially how the interaction between actors can create and facilitate societal transition processes [226].

Tomas Kåberger - *Affiliated professor at Environmental Systems Analysis/Technology Management and Economy, Chalmers University of Technology*
Tomas Kåberger is an affiliated professor at Environmental Systems Analysis at Chalmers, where he is also the Co-Director of the Energy Area of Advance. His research includes industrial energy policy, energy technology development and nuclear waste management amongst other things [227]. Currently, Kåberger is a member of the Swedish Climate Policy Council and occupies several board member or advisory positions in various instances. Previously, he has worked in many leading positions with a renewable energy focus, such as being the Director-General of the Swedish Energy Agency 2008-2011 and member/president of Svebio 1990-2008 [228].

Thomas Sterner - *Professor of environmental economics, University of Gothenburg*
Thomas Sterner is an environmental economist at University of Gothenburg, where he has founded the Unit for Environmental Economics over the past decades, which now has about forty PhD and graduate students. His research areas include amongst others Resource Management in Developing Countries and Economics of Energy Use and Climate Change. Sterner lectures about environmental policy instruments, both nationally and internationally. He has published several articles and books over the years on the subject of environmental policy instruments, their impacts in developing countries and on climate change [229].

Henrik Thunman -*Professor and Head of Division, Department of Space, Earth and Environment, Energy Technology, Chalmers University of Technology*
Henrik Thunman is a professor in thermochemical conversion at Chalmers, where he also acts as Head of Division [230]. He is an elected member of the Royal Swedish Academy of Engineering Sciences, where he acts as Vice-Chair of the Section of Chemical Engineering since 2017. His initial research focused on modelling of biomass combustion, which also was the topic of his dissertation in 2001. Since then, the research has been broadening into energy system modelling and during the last 10-years towards dual bed gasification processes, where he has been responsible for the research connected to the first-of-its-kind biomass to biomethane via gasification demonstration, the GoBiGas-plant [private communication].

Environmental actors

Alexander Ahl - *Climate activist, Fridays For Future*
Alexander Ahl is an 18-year-old student and climate activist in the school strike movement Fridays For Future, based in Lysekil. Fridays For Future is a global youth movement calling for action against climate change by striking from school to put pressure on politicians. Ahl joined the youth movement in January 2019 and works with organising local activities as well as with national and international coordination and communication. He has been involved with media as well as political forums and events, such as Almedalen political week 2019. For his high school natural science program, he specialises in marine biology at Gullmarsgymnasiet in Lysekil, where he currently studies the effects of climate change on sugar kelp as his high school graduation project. For future studies, Ahl has applied for the Marine Biology bachelor's programme at the University of Gothenburg [private

communication].

Guy Finkill - *National coordinator for Swedish Universities, Fossil Free Sweden (a subdivision of 350.org)*
Guy Finkill is the National Fossil Free Coordinator for Swedish Universities since late 2017. Fossil Free is a global movement with the aim of ending the age of fossil fuels one small community at a time [231], where he has been active since studying at Uppsala in 2016. Finkill has double master degrees, Sustainable Development from Uppsala University and Environmental Studies from the Swedish University of Agricultural Sciences. Currently, he works as Research Assistant at Lund University Centre for Sustainability Studies, where he among other things treats BECCS, negative emissions and the Politics of a Project Future [private communication].

Dag Henning - *Energy analyst, Swedish Environmental Protection Agency (Naturvårdsverket)*
Dag Henning is an energy analyst at the Swedish environmental protection agency since March 2015, where he now works in the climate policy unit. Before this, he was a consultant at Optensys Energianalys during 2005-2015 and made scenarios for sustainable energy supply and use, optimised electricity and DH production and developed energy system models. Further, Henning is a Ph.D. and Docent in energy systems. As a researcher during 1991-2005, he developed the energy-system optimisation model MODEST and applied it to, for example, DH, electricity production, emission limits and the interplay between energy supply and conservation. He has also given advice on energy system modelling and the impact of the European electricity market and been in charge of interdisciplinary PhD courses and research on energy issues [Linkedin].

Alvin Hilmersson Haag - *Environmental Officer, Environmental Administration (Miljöförvaltningen) in City of Gothenburg*
Alvin Hilmersson Haag is Environmental Officer at Miljöförvaltningen where he works with energy strategic issues in the City of Gothenburg [Linkedin]. His tasks include among other things being project manager for the development of a new energy plan for the City of Gothenburg and participating in the work on the development of the new environmental and climate program. Hilmersson Haag's academic background is from Uppsala University where he has a MSc in Sociotechnical Systems Engineering with a focus on energy systems [private communication].

Boel Lanne - *President, Swedish Society for Nature Conservation (Naturskyddsföreningen) in Bohuslän*
Boel Lanne is the president of the Bohuslän division of Swedish Society for Nature Conservation, where she's been active the past 27 years. As president, she interacts regularly with the national division of SSNC as well as the other regional divisions. In addition, she is member or president of several subdivisions of SSNC Bohuslän [Linkedin]. Since 8 years, Lanne is retired from her previous work as a researcher in biochemistry and environmental science, in which she has a PhD [private communication]. Additionally, she is active in Miljöpartiet where she is part of the municipal council of Öckerö [232].

Peter Roberntz - *Senior Forest Advisor, WWF*
Peter Roberntz currently works as Senior Forest Advisor at the World Wildlife Fund, WWF, where he's worked since 2007 on issues related to bioenergy, land use and forestry as well as aid in Sweden and Africa [Linkedin]. Roberntz is a Forester (Jägmästare) with his academic background at the Swedish University of Agricultural Sciences where he got a PhD in 1996 and continued working for a few years as a researcher and project manager. For six years, he worked as Head of Operations at Swedish FSC, where he among other things, coordinated the management and development of the Swedish standard for FSC-certified forestry [private communication].

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