“The Nordic Region – a frontrunner of the decarbonised energy system”

Workshop Synthesis Report

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Background

To meet the goals outlined in the Paris Agreement and keep the global temperature increase below 1.5ºC, the transformation and decarbonisation of the current energy systems is of profound importance. However, deciding on how the future energy systems shall be designed to guarantee energy security, social and environmental sustainability, as well as energy accessibility and affordability of energy across the population, is not an easy task.

While energy models have served for many years as useful tools to inform energy policymaking, the increasing complexity and interrelatedness of various dimensions of energy has led to a situation, in which existing modelling tools do not capture enough of the technological, geographic, societal and environmental details important for designing a decarbonised energy system. The EC-funded H2020 project, SENTINEL, which stands for Sustainable Energy Transitions Laboratory, seeks to overcome this drawback and develop a new energy system modelling framework.

Nevertheless, designing a multifaceted modelling suite brings along certain challenges. On the one hand, different energy models represent different technical functionalities and encompass different geographical and time resolutions. On the other hand, even the most solidly designed modelling tool, accommodating the newest and most innovative programming techniques, will remain redundant if the needs and concerns of people are not considered. In particular, those who are using energy models and their results in their professional life are crucial in making decisions about energy futures. In this context, there exists an additional threat that the modelling runs, and decisions based thereon will be contested by some social actors, as long as they are conducted 'behind closed doors'.

In order to overcome these shortcomings, SENTINEL has applied a carefully defined, participatory approach. First, we are investigating how to adjust modelling tools and check their behaviour in different geographical and socio-cultural contexts. In that sense, we have selected three case studies: national (focusing on Greece), regional (dedicated to the Nordic region) and continental (dealing with Europe). Second, from the earliest phases of the project, we have actively engaged stakeholders representing the policymaking sphere, energy industry, non-governmental organisations (NGOs) and scientific community, to understand what the needs of modelling users are. Finally, by involving external actors in SENTINEL models' application processes in a transparent way, we are aiming to give an overview about how the models work, and what kind of modelling outcomes can be driven by changes of different assumptions and parameters.

This document presents one of the steps undertaken to realise the actions described above. It summarises the online workshop "The Nordic Region – a frontrunner of the decarbonised energy system" that took place on 4 November 2020, with almost 30 energy experts from the Nordic countries and from the SENTINEL consortium attending. The report captures our discussion and findings tackling the different dimensions of the Nordic energy system, which show a complex mixture of points essential for delivering a decarbonised energy future in this region. The results of this exchange indicate relevant issues of the Nordic energy landscape, their accompanying challenges and implications, which should not only be considered by energy models, but also should constitute a base for further inspiring discussions among decision-makers and practitioners.

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1. Introduction

The institutional collaboration between Denmark, Finland, Iceland, Norway and Sweden in the climate and energy field is strong. Already in October 2015, the Nordic Council of Ministers recognised a need to strategically review Nordic cooperation on energy, then develop proposals to bring specific ideas to life and further enhance the Nordic potential in the energy field. In response to the Paris Agreement and accelerating energy transitions around the world, Nordic Prime Ministers announced at the beginning of 2019 a political declaration of the Nordic Carbon Neutrality (Nordic Cooperation, 2019). This step aimed to not only have Nordic countries take a leading role in efforts to fight against climate change, but also aimed to create an opportunity for businesses and the economy as a whole, while ensuring socially and environmentally sustainable growth.

Since most energy models are used within national, continental or global contexts, from a modelling point of view, this political and institutional development has created a great opportunity to consider how such enhanced regional cooperation in the energy field could be encompassed by a modelling framework, like SENTINEL. Moreover, this perspective has become even more appealing, as Nordic countries have demonstrated technological advancement and innovation of global relevance. In the area of energy, it refers to many aspects, such as: steady decoupling of GDP from energy-related CO_2 emissions, a highly decarbonised power sector and the role of hydropower therein, a mature electricity market, as well as the electrification of transport, heat supply and industry, just to name a few.

Against this backdrop, the Nordic Energy Research released in 2019 and 2020 the "Tracking Nordic Clean Energy Progress" reports (Nordic Energy Research, 2020). They evaluate the advancement of the Nordic region towards a carbon neutral society by 2050, which is discussed in relation to the 'Carbon Neutral Scenario' (Nordic Energy Research & IEA, 2016). These represent a good starting point for gaining a better understanding of how the regional peculiarities can be captured by the modelling tools.

Yet, although these publications holistically present the pathway and drivers to a decarbonised Nordic energy system, it has not been clear to which extent they reflect concerns, needs and demands of stakeholders interested in the future Nordic energy system. To this end, in SENTINEL, we want to investigate how to best deliver suitable and applicable modelling solutions. Thus, it has been essential for us to discuss the relevance of our work and gain first-hand insights into critical topics and issues for the medium- and long-term energy transition in the Nordic region from stakeholders.

To realise this objective, we organised an online workshop "The Nordic Region – a frontrunner of the decarbonised energy system". On the next pages of this report, we will present our approach to engaging stakeholders together with the workshop's proceedings. Then we will present the findings from this event, which, if not indicated otherwise, reflect the opinions of the participating stakeholders. The final part of this document outlines conclusions and the next steps.

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2. Stakeholder engagement approach and workshop's proceedings

The workshop "The Nordic Region – a frontrunner of the decarbonised energy system" took place on the 4th of November 2020. The initial idea for carrying out an exchange with stakeholders was to organise a physical meeting in one of the Nordic countries in June 2020. The outbreak of the COVID-19 pandemic required a change of our approach: the preparations shifted in time and the workshop was organised as an online event on Zoom. Altogether, almost 30 representatives of the policymaking sphere, energy industry, NGOs, scientific community as well as SENTINEL consortium participated. The list of participants can be found at the end of this report.

The workshop was divided into four main parts: **(1)** Opening plenary session, **(2)** Parallel breakout sessions – round I, **(3)** Parallel breakout sessions – round II, and **(4)** Closing plenary session. Each of the parallel breakout sessions consisted of six thematic breakout rooms, which touched upon different aspects of the Nordic energy system: **(i.)** Transforming the power sector; **(ii.)** Sector coupling: implementing smart energy systems and P2X solutions; **(iii.)** Decarbonisation of industry and Carbon Capture and Storage and Utilisation; **(iv.)** Energy efficiency and smart buildings; **(v.)** Environmental aspects and implications; and **(vi.)** Socio-economic aspects and implications. **Table 1** below presents the structure of the workshop.

Time	Agenda item	
10:00-10:25	**Opening plenary session**	
10:25-11:20	**Parallel breakout sessions: Defining your needs regarding the models – round I**	Session 1: Transforming the power sector
		Session 2: Sector coupling: implementing smart energy systems and P2X solutions
		Session 3: Decarbonisation of industry and Carbon Capture and Storage and Utilisation
		Session 4: Energy efficiency and smart buildings
		Session 5: Environmental aspects and implications
		Session 6: Socio-economic aspects and implications
11:20-11:40	**Coffee break**	
11:40-12:35	**Parallel breakout sessions: Defining your needs regarding the models – round II**	Session 1: Transforming the power sector
		Session 2: Sector coupling: implementing smart energy systems and P2X solutions
		Session 3: Decarbonisation of industry and Carbon Capture and Storage and Utilisation
		Session 4: Energy efficiency and smart buildings
		Session 5: Environmental aspects and implications
		Session 6: Socio-economic aspects and implications
12:35-13:15	**Closing plenary session**	

Table 1. The structure of the workshop "The Nordic Region – a frontrunner of the decarbonised energy system"

In order to select the themes of the breakout sessions with relevance from the perspective of the ongoing energy transition in the Nordic region as well as from the modelling perspective, we undertook three steps. First, we reviewed existing literature to learn about energy policy priorities in the Nordic countries. Second, we consulted our ideas with the representatives of the Nordic Energy Research Council. Third, we discussed the prominence of our approach within the SENTINEL consortium to learn how the selected topics could be seized with the models applied in the project. As a result, each of the thematic sessions was facilitated by the SENTINEL modellers, who, in their own models, deal with various issues related to the scope of the selected themes.

It was important for us to invite stakeholders to the workshop who embody differentiated views on the critical issues of the Nordic energy transition. Thus, we sent numerous personalised invitations to carefully selected representatives of the Nordic climate and energy community. Our stakeholder mapping process encompassed literature and online research, included a snowball effect and was double-checked with an external expert on the Nordic region. Again, the SENTINEL modellers were consulted at that point and asked about their

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recommendations. A week before the workshop we contacted registered participants and asked about their preferences regarding two thematic sessions and which they would like to attend during different rounds of the parallel breakout rooms. This information was compelling for us to guarantee that in two different rounds of thematic sessions, the created subgroups would be diverse and the exchange between their members multidimensional.

While contacting registered stakeholders we shared with them a short document produced in a collaboration with SENTINEL modellers. It described the thematic scope of each of the sessions and research questions, which would guide stakeholders during the exchange. Being inspired by the "*Three types of knowledge tool*" method (ProClim, 1997) we structured the proceedings of the thematic sessions around three questions relevant from a modelling point of view and the progress towards Nordic carbon neutrality. These questions were:

1. Where are we?
2. Where we want to get to?
3. How do we get there?

The objective behind answering the first question was to understand at which point currently the Nordic region is regarding the energy transition. Furthermore, it aimed at understanding current stakeholders' perception of specific processes and issues in the climate and energy realm in the Nordics. Sketching such contextualisation set the stage for further discussion.

The final objective of the Nordic energy transition – carbon neutrality – has been already defined and politically backed. Yet, we still wanted to use the second question to validate, whether there exists unanimity among the stakeholders regarding this goal.

The aim of the last question was to identify crucial issues to be considered in order to achieve carbon neutrality. It was essential for us to comprehend and draw potential pathways, which will lead to this objective. These pathways should include technological developments, social processes, market and regulatory mechanisms as well as environmental aspects.

SENTINEL modellers had flexibility in facilitating their sessions, but they kept these three questions in mind while moderating the discussions. The following pages present the findings of each of the thematic session.

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3. Results of the parallel breakout sessions

Session 1: Transforming the power sector

SENTINEL facilitators: Bryn Pickering and Arsam Aryandoust (ETH Zurich)

The first thematic session was dedicated to the transformation of the power sector, which in the Nordics is already close to being decarbonised. While the remaining effort to achieve full decarbonisation is relatively small compared to the rest of Europe, the workshops' participants noticed that further decarbonisation of the Nordic power sector does face certain challenges related to specific aspects of the whole energy system.

One of the steps leading to decarbonisation of the power sector is the integration of more wind power in line with 2050 climate goals. According to some calculations, wind power should be responsible for 30% of electricity generation in 2050, compared to 7% in 2013 (Nordic Energy Research & IEA, 2016). Further utilising the vast availability of land area could contribute to developing more onshore wind power capacity. That, in combination with a large amount of available bioenergy, could increase renewable-based electricity generation and potentially strengthen the Nordic region's position to become exporter of electricity to northern European countries (e.g., Germany). In addition to the potential of the Nordics becoming an electricity hub for Europe, its hydro reservoirs could also play a significant role in balancing European variable renewables (see also: Gullberg, 2013; Gullberg, Ohlhorst and Schreurs, 2014).

Yet, participants of this thematic session noted that these reservoirs might not be a panacea of dispatchable energy. As their limited capacity and their dispatchability is highly weather-dependent, changing weather conditions related to climate change could exacerbate these issues. As an alternative, stakeholders mentioned that the heat sector could act as a balancing mechanism. That also holds true for nuclear power, which cannot be assumed to be out of the picture. Although it is economically unfavourable, there is no strict target for its removal, and in Finland there are even plans to commission new nuclear block(s).

Decommissioning conventional power plants in favour of wind power will require electricity transmission line reinforcement. Fossil fuel-based generation units close to consumption centres will be decommissioned, for example in the vicinity of Stockholm. Offshore wind power will be concentrated in countries with the greatest access to the North Sea. Without transmission line reinforcement, there is a risk that it will not be possible to share greater wind generation across all Nordic countries. Decommissioning local generation may also cause population centres to become transmission islands, whereby greater dependence on remote generation is not matched by the capacity of high voltage transmission lines. Given this expected increase in distance between supply and demand, it is unclear who exactly will bear the costs for grid transformation.

High levels of industrialisation in the Nordics create additional challenges for the power sector's transformation. For instance, there are industries which cannot operate in certain areas due to lack of power. Increasing electrification of the whole energy system could further threaten industries, if based upon an unstable electricity supply. Moreover, cross-sectoral electrification, involving the transportation and heating sectors, again raises the issue of who will pay for this transformation. As an answer, the participants of this thematic session identified private actors willing to transform the power sector even more than suggested by existing models. A similar critique of existing modelling tools concerned solar power, which is

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not currently modelled as a key contributor of the power system transformation, because of a dominating perception that its use could result in stranded assets across other technologies.

In the context of electrification of industry, stakeholders also pointed to hydrogen use, which will be needed in vast quantities for direct reduction of iron in steel production. Since using hydrogen for industry could cause a significant increase in electricity consumption, the decarbonisation of industry would be counterproductive if electricity is not supplied by renewables. One of the ideas to prevent such a situation was to import hydrogen from other European countries who are intending on becoming leaders in hydrogen production (e.g., France).

Ultimately, stakeholders mentioned that transforming the Nordic power sector requires better governance and more institutional cooperation between the countries, which, despite the joint Nordic Carbon Neutrality Declaration (Nordic Cooperation, 2019), currently seems to be insufficient. The aforementioned issue of international transmission illustrates this shortcoming well. Additionally, other countries, such as Lithuania, Latvia and Estonia, should be involved in this process too.

Session 2: Sector coupling: implementing smart energy systems and P2X solutions

SENTINEL facilitators: Jakob Zinck Thellufsen and Miguel Chang (Aalborg University)

The second thematic session was dedicated to the implementation of smart energy systems and P2X solutions. The electrification of transport and heat supply are important measures for switching both sectors to renewables. While sector coupling increases potential system flexibility, it presents major challenges in terms of infrastructural development (despite relatively huge current fleet of electric vehicles and well-established district heating grids in the Nordic countries) and in terms of growing complexity for modelling.

The exchange with the workshop's participants concentrated on five topics related to sector coupling, unveiling important aspects, which should be considered during the modelling stage.

The discussion started with a statement that electric vehicles and P2X infrastructure have to be implemented to fit both the needs of passenger transport and heavy transport, in addition to demands in power plants and industry. Participants of this session noticed that passenger transport could rely on biofuels as a short-term solution but that these should be replaced by electrification in the long term. That, however, can trigger a challenge in terms of resource constraints in the biomass supply, when looking at the use of biofuels not only as an alternative fuel for transport, but also for covering power plants and industrial demands, which in turn could lead to an inefficient production loop, where those same plants provide electricity for further synthetic fuel production. Furthermore, additional backup power generation capacity would be needed for P2X solutions.

From a modelling perspective, the discussion revealed important issues, uncertainties and shortcomings of existing modelling tools. For example, stakeholders pointed out that the time component is essential to reflect on the expected shifts in transport electrification and fuel demands. They noticed that the effects of EVs on local networks are not always captured in scenario representations used to compare EV solutions with production and use of synthetic fuels for transport. Additionally, it is important to capture the differences in the transport fleets

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between the different Nordic countries, and between the Nordics and other EU countries. Moreover, the participants of this session posed a question inquiring to what extent e-roads could be considered as a solution, and in which areas. Further aspects concerned how the efficiency of different vehicle types is considered in the energy system modelling and the uncertainty about the costs of transporting fuels from one place to another, which could impact scenario outcomes and comparisons. Last but not least, the participants mentioned that the increasing share of EVs needs to be supplemented by ongoing discussions about new energy tariffs and schemes to enable its further uptake.

Afterwards, the discussion shifted towards a question to what extent it is feasible that heavy goods vehicles (HGV) will become effectively decarbonised by using electricity and batteries, considering their differentiated technical requirements and purpose, such as weight, cargo and autonomy. The participants noted that HGV and maritime transport can rely on P2X solutions, such as synthetic fuels or H2, instead of being fully electrified, whereas synthetic fuels could serve as 1-to-1 replacements for current fuels and H2 could be produced via electrolysis using fluctuating renewables. They also pointed out specific challenges related to the deployment of charging infrastructure, which can halt electrification of transport and HGV, and affect the security and safety of handling H2 fuel, as in the 2019 accident in the Oslo area (Randall, 2019).

In the context of the modelling, the stakeholders concluded that it can be more complex to represent synthetic fuels than H2.

The next point of the discussion focused on the heating system that in the Nordic countries needs to be designed to fit a development towards smart energy systems, what includes the 4th generation district heating. In this context, the participants of this session confirmed that heat pumps and heat storage can provide additional flexibility cost-efficiently, being effective solutions to integrate variable renewable energy sources. Nevertheless, they pointed out that specifically heat pumps might not be suited for quick ramping, so other options could be in terms of providing flexibility when handling excess electricity production. This technology can, however, be used as efficient heating solution in areas with no district heating or where it is not feasible, especially since other not-very-efficient technologies, such as direct electric heating and air-to-air heat pumps, are still in use.

Whilst there was an agreement between stakeholders that the current models used in the Nordics generally cover the heating systems well, this does not hold true for how the heating should be regulated when including P2X in the energy system (e.g., old school planning vs. market-based approach). Additionally, they admitted that there must be a balance between investments and excess heat utilisation (e.g., adequately capturing costs in additional infrastructure).

The last two merged topics of this session were supposed to redirect the discussion towards grids. First, in the sense that system integration will help in lowering the strain on the electricity grid coming from an increased heating and transport demand supplied by electricity. Second, that heat pumps, waste heat and thermal storage need to be implemented in the district heating grids to accommodate for smart energy systems. However, both of these statements elicited various topics, relevant for other thematic sessions included in the workshop.

The stakeholders stated that while considering sector coupling, the electrification of heavy industry must also be considered, however it remained unclear how much of it should be electrified. These considerations have led to further insights and questions, e.g., that industrial

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users can also be heat producers; how to handle industrial CO_2 emissions and if CCS would be a proper solution; or whether the sources and sustainable use of biomass for bio-intensive systems should be further identified, taking into account that green carbon can be used for green fuels or CCS.

The participants expressed concerns regarding the siting problems concerning different technologies and accompanying aspects. For example, they wondered whether the electrolyser facilities should be placed nearby some of heavy industries; where and how new power plants should be installed, considering not only non-mainstreamed technologies (i.e., offshore floating wind turbines), but also the public resistance; or where to build the CCS units in the context of balancing biofuel conversion with available carbon and biomass resources (and a limited use of biofuels for specific purposes, e.g., HGVs or aviation).

That provoked further thoughts regarding the challenge of how to justify the development and implementation of these aforementioned technological solutions in a socio-economically responsible manner; how to substitute incomes in the future, which so far have been covered by traditional, fossil sectors, like oil and gas sectors in Norway; or how carbon is managed, reduced and also reused for biofuel conversion in the system. Eventually, stakeholders pointed out that while storage will be essential to add flexibility to the system, it might bring new challenges for the hydrogen pipes, which actually could prove to be cheaper than new overhead electricity lines. Similarly, they expected the costs of electrolysers to go down as well.

From a modelling perspective, this discussion revealed that it can be difficult to couple and get models to converge (e.g., energy system and power system models), especially if the system flexibility will come from different sources (like batteries, data centers, hydrogen production, heating etc.). Additionally, it became clear that the international fuel prices (e.g., green H2 vs. blue H2) will cause uncertainties, regrading whether the current prices will sustain or go toward fossil fuel prices.

Session 3: Decarbonisation of industry and Carbon Capture and Storage and Utilisation

SENTINEL facilitators: Gabriel David Oreggioni (Imperial College London) and Mark Roelfsema (Utrecht University)

The third thematic session was dedicated to the Nordic industrial sector. While it is already comparatively energy- and resource-efficient, further improvements will require technological innovation, including substantial application of Carbon Capture Storage and Utilisation (CCS and CCU). Currently, within the industrial sector in the Nordic countries, electricity, biofuels and waste are the most used vectors for energy supply (IAE, 2017). While combustion emissions are the largest contributor to fossil CO_2 emissions from this secondary sector, the emissions from fuel production as well as process emissions (especially from cement and steel industries) also play a significant role (Crippa et al., 2019; Oreggioni et al., 2020).

The decarbonisation of industry will be important for achieving the Nordic carbon neutrality goal, but imply specific challenges, such as economic consequences and competitiveness; resources and environmental trade-offs; societal concerns and public acceptance; or the incorporation of technology. The discussion with stakeholders shed light on many of these topics and revealed linkages to other thematic sessions.

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The participants of the workshop confirmed that steel and cement industries, in addition to chemical production, are key sectors for fulfilling emission reduction targets. However, depending on specific Nordic countries, the focus might differ. For example, Norway should prioritise emission reductions in the cement and metallurgic sectors.

The use of hydrogen can enable the decarbonisation of industries, but, here again, the stakeholders noticed differences between countries. While Norway is considered to be a "hydrogen hope" for the rest of Europe, it is actually Sweden that is developing the largest H2 projects. In both countries, the potential to develop green H2 is related to large offshore wind farms (in case of Norway this concerns its northern part), creating an opportunity to balance offshore power. Nevertheless, stakeholders shared the observations that Norway should primarily continue to develop more renewables capacities. This discussion triggered a different point about Iceland's hesitation to share green energy with other countries, due to lack of support from the side of policymakers and the public. Citizens do not want more mega power projects in Iceland and are prioritising nature preservation instead.

The Nordic region as whole, has a competitive advantage to further develop H2 projects. This derives from an existing well-developed oil and gas industry and a high potential for variable renewable energy production, requiring the deployment of possible storage technologies. "Blue H2 "can be produced through methane reforming, whilst "Green H2" can be obtained thanks to water electrolysis using renewable electricity or biomass or waste gasification. In the case of blue H2, more investments in CCS technologies are needed to decarbonise its production. Particularly, captured CO_2 could be injected in aged wells to increase productivity or be used as feedstock for chemical production. Moreover, the participants of this session agreed that there is limited potential for hydrogen use in the heating sector, as it would be less efficient, requiring gas use and more electricity input.

The attempt to uncover the future fuel basket for the industrial sector as based on high shares of renewable electricity, bioenergy with carbon capture and storage (BECCS) and H2, also revealed existing differences between the Nordic countries. There is a potential to develop energy technologies using waste, but here, a further development in this direction depends to a great extent on the EU legislation for negative emissions and limits or caps for air pollutant emissions from small and medium waste fueled combustion sources.

In that context, Iceland represents an interesting example, where there is a very high acceptance of CCS methods: not for conventional CCS, but for CCM (carbon capture and mineralisation) as in the Carbfix project (Carbfix, 2021). In terms of investments in CO_2 storage hubs and CO_2 transport infrastructure, stakeholders discussed that Norway could develop a CCS business model to export to the rest of Europe. However, that caused further considerations. First, considering that Norway already would need to capture 7 million tons of CO_2 per year to allow for 85% of emission reduction from the industrial sector by 2050, what are the available capacities for CCS? Second, how would this be achieved: by the use of pipelines or ships? Third, how much would such solution cost? Last, but not least, stakeholders discussed the potential of chemical utilisation of CO_2, especially from H2 production units and refineries.

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Session 4: Energy efficiency and smart buildings

SENTINEL facilitators: Souran Chatterjee (Central European University), Vassilis Stavrakas and Georgios Giannakidis (University of Piraeus Research Centre)

Decarbonisation of the energy sector by 2050 requires balancing energy supply with energy demand and the workshop's fourth thematic session concerned the latter, focusing on energy efficiency and smart buildings. The discussion was built around topics related to general energy demand by 2050, energy efficiency measures and RES systems, as well as to smart buildings and flexibility services, and included potential effects on modelling.

The participants of this breakout group noticed that in the Nordic region, energy demand has been decreasing in the last decade, indicating an optimistic trend. That is in line with the Carbon Neutral Scenario, according to which, the energy consumption of the building sector will decrease by 27% by 2050 comparing to 2013 levels (Nordic Energy Research & IEA, 2016). As the main challenges and opportunities concerning energy demand in the Nordic region, stakeholders identified the high indoor heating set point, old building stock, and exponential market increase in electric vehicles (EVs). As a general comment, the stakeholders noted that positive behavioural changes can materialise when people perceive them as an opportunity instead of a threat. An example of this is changing indoor heating set points (e.g., in Sweden), which provides opportunities to increase efficiency without compromising comfort, ideally using smart monitoring systems. Some exemplary, already implemented measures in that context are heat pumps replacing direct electric heating and smart thermostats enabling flexibility and demand response. Stakeholders pointed out another interesting phenomenon related to the increase of EVs in the Nordic market. For example, 80% of new vehicles sales in Norway are electric vehicles. Since EV owners primarily charge their cars at home, there is a shift of electricity demand towards the residential sector. Charging patterns influence peak electricity demand and the demand profile overall.

The discussion revealed a high potential for refurbishment of building stock in Nordic countries (especially those built before 1975), which is currently very slow. Considering the population growth in Nordic cities, the demand to refurbish existing buildings should increase at a quicker pace. While the new building policies in Nordic countries are strong, energy consumption remains high in the region, because existing buildings are not of the same high standard. Furthermore, since the electricity prices are low (e.g., in Sweden), the present incentives aimed at reducing electricity demand are insufficient. Also, due to cultural habits, like for instance in Sweden, where people tend to overheat their homes in winter, energy consumption per building is still relatively high. According to the stakeholders, there is a rather limited interest in defining high performance buildings in the region (at least in Sweden) like passive house or nearly-zero energy building (NZEB). In this context, the measures which could provide substantial energy savings encompass energy-efficient water heating systems, and heat pumps continuing to replace existing (direct electricity) heating systems.

The topic of smart buildings and flexibility services has been very intertwined in the above conversations. They concerned, for example, the importance of demand response to monitor electricity patterns, especially with the increasing use of EVs in the residential sector. Smart metering will be crucial for generating data, and thermostat setpoint "setback analyses" will help provide insights into behavioural change and energy demand. These together should contribute to modelling to provide essential output presenting the potential for energy savings.

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Section 5: Environmental aspects and implications

SENTINEL facilitator: Cristina Madrid-López (Autonomous University of Barcelona)

The application of technologies leading to a decarbonised energy system will result in domestic and externalised environmental impacts. To explore that, the fifth thematic session focused on aspects and implications of the use of biomass for heating and electricity production and on the increasing demand of batteries due to transition to electric vehicles (EV). The participants of this session explored impacts related to land use, extraction of minerals, biodiversity and water. The discussion was framed around five claims: (1) Renewable energy can provide 100 % of the energy required for households, economic sectors and administration; (2) Supply of raw materials is the main risk faced by implementation of renewable energy system technologies; (3) Battery and fuel cells are the preferred formats for light and heavy transport vehicles; (4) Biomass is the best alternative for individual and district heating; and (5) Land use constraints and environmental impacts will affect the success of biomass as a heat and fuel source.

Stakeholders in general tended to see potential to meet 100% of renewables in the mix that provides total energy demand, depending on if it this referred to for 2030 (less likely to achieve this goal) or 2050. Cases vary between countries. Whereas in Sweden, nuclear energy was presented as a 'must' to support electrification, Iceland's current contribution of 84% renewable energy set an optimistic view about the goal. Participants showed concern about the lower potential of some EU countries that would make a full transition within all Europe difficult.

Realising the pathway to carbon neutrality will require significant amounts of raw materials to produce the equipment, infrastructure and vehicles. In that context, stakeholders agreed that potential supply restrictions of raw materials are the main risk for implementing renewable energy system technologies. This problem particularly concerns the raw material inputs needed for EVs, photovoltaics (PV), batteries and wind turbines.

Since the Nordic's transportation sector needs to transform to cleaner fuel sources to meet carbon neutrality, a rise in EVs, hybrid and fuel cell vehicle use (especially for light and heavy transport vehicles) will require a significant increase in the level of battery production. Against this backdrop, the participants of this session voiced concerns over range and total tonnage constraints with battery usage. In addition, since fuel cell technologies require the extra step of hydrogen production, they discussed whether this would be a green hydrogen-based system. Finally, the stakeholders shared their thoughts regarding the circular economy of recycling batteries after their lifecycle instead of disposing them, which will depend, for example, on the dominant types of batteries.

Biomass combustion is a major heat source in Nordic countries, but the attendees of this session contested the claim that biomass is the best alternative for individual and district heating. While biomass can be stored relatively easy, it is neither particularly energy dense (compared to natural gas for example) nor environmentally friendly, given the lifecycle of the carbon emissions. Moreover, its use and access differ between the Nordic countries and not all of them are keen to sacrifice biodiversity to produce more bioenergy. In that context, the stakeholders discussed other preferred alternative sources to biomass, like heat pumps, emphasising different methods within the region. For instance, in Iceland, where 90% of heat comes from geothermal, increasing biomass does not reach economies of scale, and therefore, is not cost effective. The issue of externalisation also came up regarding biomass-

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related impacts, as in some of the northern countries this resource is mostly imported, leading to transboundary issues. That concerns, for example, Sweden or Denmark, that is depending on 100% import for bioenergy and outsources biomass feedstocks from countries with potentially less strict environmental regulations. That, in turn, leads to a need to consider externalisation of environmental impacts by the modelling tools.

Considering existing trade-offs between nature conservation and energy production, stakeholders agreed that the success of biomass as a heat and fuel source is dependent on land use constraints and various environmental impacts. That holds true especially in the view on stricter sustainability criteria issued by the updated Renewable Energy Directive. From a modelling perspective, these issues lead to questions, such as which indicators and criteria for various biomass feedstocks should be measured as "truly" sustainable and how to include them in life-cycle analysis, also taking into account their transport.

Session 6: Socio-economic aspects and implications

SENTINEL facilitators: Diana Süsser and Hannes Gaschnig (Institute for Advanced Sustainability Studies) and Jakob Mayer (University of Graz)

The last of thematic sessions looked at the Nordic energy transition through the lenses of the social and economic aspects. These two dimensions are important, since the clean energy transition should be socially sustainable, secure social inclusiveness towards renewable energy and be an opportunity for business and innovation. In that context, this session's discussion concerned issues related to the acceptance of a larger contribution of Nordic countries to overall EU targets, the kind and combination of climate policy instruments to achieve these targets, and how they affect inter alia job creation. Each of these topics could be investigated with various energy modelling tools, and stakeholders discussed if state-of-the-art models address relevant aspects and mechanisms and how they could be improved.

The discussion about the acceptance of higher Nordic contributions to overall European decarbonisation targets revealed the complexity of this topic. Stakeholders generally agreed that there is a broad consensus to support higher Nordic efforts, but it remains only a political issue, lacking a societal debate. As there is no clear political positioning to the subject, it can be expected that not all political parties will express their support for effort sharing. Since the Nordic countries have already set ambitious targets compared to other EU member states, the political acceptance is higher if the effort sharing takes place across the region. A coordinated discussion from the European Union's side regarding the disparity in contributions from different member states seems to be essential to create political and societal awareness for the topic and start a broader debate thereon. Nevertheless, the Nordic commitment to carbon neutrality remains motivating for other countries to be more ambitious in setting their national decarbonisation targets.

Against this backdrop, the participants of this session noticed that *if* the Nordic societies would agree to even a deeper decarbonisation and accept the effort sharing, the willingness to pursue both objectives will depend on how smoothly they would be implemented. On the one hand, social acceptance cannot be taken for granted. Stakeholders mentioned that we must take into account examples like increasing protests against new renewable infrastructures and demands for nature protection (like in Iceland and Norway) or focus on national energy balances instead of considering renewable energy export potential (like in Sweden). On the other hand, stakeholders noted that, so far, it has been easy for the Nordic countries to reach

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their energy and climate targets, but this is expected to change. For example, a 70% emissions reduction from transport sector in Sweden by 2030 will require not only technological change, but also a substantial change of lifestyles, in order to achieve the last 5-10% of emissions' reduction. The application of specific instruments, like consumption-based targets, which might cause additional high costs for people, could be introduced, but may receive less acceptance from the society.

Different climate policy instruments, like CO_2 prices or standards, can have an impact on burden distribution and can lead to social divisions, such as between urban and rural areas. The stakeholders expressed the opinion that climate policy measures should be designed in a way that will allow for a just transition. This requires not only a broader perspective, which goes beyond current policies, but also a bundle of policy instruments across different governance levels to better account for distributional impacts. The latter might be challenging, because sometimes people from different political parties are in power at the national level and at the municipal level. Nevertheless, there are already promising examples, like in the transport sector, which, although still fossil fuel-based, has experienced steady progress towards decarbonisation, stimulated by a policy-mix of carbon price and support for e-mobility and public transportation. Last, but not least, the attendees emphasised the role of communication and education to create awareness for the need of climate policies among the public. Social acceptance for carbon neutrality and the implementation of necessary measures to achieve it are essential. In that context, the COVID-19 pandemic showed that society as a whole is very resilient and can accept policy-driven changes, if they serve a common good. Thus, responsible policymakers should develop coherent and convincing narrative that will frame climate actions and the energy transition in a way that it will be understandable for all parts of the society, and clearly define where we have to go and what changes are needed to get there.

The discussion dedicated to the labour market revealed that in the context of achieving Nordic carbon neutrality there is a lack of clarity regarding distributional effects. More specifically, while decarbonisation is supposed to have positive effects on creating more and better jobs, there is a lack of evidence, where jobs are created and where potentially not. Moreover, stakeholders called for a halt to the comparison of "fossil fuel jobs" with "renewables jobs", because the former will disappear anyway. Instead of that, they suggested to focus on alternative co-benefits, such as health benefits and sustainable cities.

The presented insights exposed concrete issues, which should be considered while proceeding with modelling the Nordic and European energy transition. First, the modelling of policies and policy changes, including the societal acceptance such as effort sharing, should be improved. Second, energy models should better capture societal behaviour, such as walking and cycling in transport modelling, and include impacts on energy demand due to different individual preferences for working from home or in office. Third, the modelling of distributional effects of the energy transition, specifically in terms of regional employment gains and losses should also be improved.

Beyond the modelling efforts, stakeholders emphasised the need for a public debate that addresses different implications and benefits of the energy transition. Combining modelling tools with storytelling will allow greater understanding of societal preferences for the design of the transition and create political and social acceptance for measures needed, in order to make a just transition not only happen in the Nordics but across Europe.

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4. Conclusions and outlook

The discussions at the workshop revealed meaningful viewpoints that should be considered in future work in SENTINEL. The design approach of the thematic sessions proved to be appropriate in better understanding the important current issues of the Nordic energy transition, in confirming the agreement about the need to achieve carbon neutrality, and in uncovering the components of the potential pathways leading to this objective. Based on these findings we are able to draw the following conclusions:

First, as each of the thematic sessions showed, different aspects of the Nordic energy transition cannot be analysed separately. Processes or changes in one element of the Nordic system influence its other parts. This insight confirms that as current energy systems become more intertwined, the complexity will even increase in the future. Thus, for analysis of the Nordic energy transition all possible dimensions, (technological, social, economic, political, environmental and regulatory) must be taken into account.

Second, while our ambition in SENTINEL has been to follow a regional approach, the results of the exchange with stakeholders demonstrated that it might be inaccurate to only speak about a unified Nordic energy system. It is rather a heterogenic compilation of different national energy systems, representing concrete characteristics and specificities. Moreover, they depend also on external processes related to other jurisdictions, such as the European Union, the Baltic states, or countries supplying particular resources. To overcome this challenge, a more precise understanding of the different national contexts is also required.

Finally, from a modelling perspective, our findings reflect a need for further improvement of existing modelling tools. The current energy system models cannot answer all the questions and concerns raised by the stakeholders. This motivates us to continue working on development of the SENTINEL suite. Yet, the uncertainties remain as to whether it will ever be feasible to answer some of the questions through energy system models. Probably not, therefore we think that in those cases modelling should serve as an additional tool for stimulating a transparent and inclusive public debate towards holistic decision-making.

Overall, the evaluation after the workshop showed that participants were satisfied in joining this event. The collected feedback and lessons learned will help us realise the next steps in the SENTINEL project. Based on the information generated at the workshop, we will shift into a models' application stage. Once the first round of modelling runs is completed, we will be happy to share the outputs with key experts and stakeholders, and consult them on how to further improve our work.

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About SENTINEL

The transition to a low-carbon energy system will involve a major redesign of the energy system, primarily around renewable sources, in accordance with 2030 and 2050 targets that the European Commission has defined. The interdisciplinary consortium develops an open-source platform SENTINEL, which stands for the Sustainable Energy Transitions Laboratory. This platform will consist of well-suited energy models to support the European Energy Transition. Please find an overview of project partners and modules below.

Please find further information about SENTINEL here.

Module	Model	Focus	Developer
Social and Environmental Transition Constraints	QTDIAN*	Drivers of technology diffusion	Institute of Advanced Sustainability Studies (IASS), Germany
	ENVIRO*	Life-cycle analysis of energy technologies	Autonomous University of Barcelona (UAB), Spain
	ATOM	Technology adoption by individual agents	University of Piraeus Research Center (UPRC), Greece
Energy Demand	DESTINEE	Electricity demand generator	Imperial College London, UK
	BEVPO	E-mobility diffusion, utilisation, and charging	ETH Zürich, Switzerland
	HEB	Technology-specific building sector demand	Central European University (CEU), Hungary
	DREEM	Electricity demand response and flexibility	University of Piraeus Research Center (UPRC), Greece
System Design	EnergyPLAN	Energy supply: focus on sectoral integration	Aalborg University (AAU), Denmark
	Calliope	Energy supply: focus on geographical integration	ETH Zürich, Switzerland
	IMAGE	Global integrated assessment model	Utrecht University (UU), Netherlands
Economic Impact	EMMA	Top-down electricity market simulation	Hertie School (HSG), Germany
	BSAM	Agent-based capacity bidding simulation	University of Piraeus Research Center (UPRC), Greece
	WEDGYN	Computable general equilibrium impacts	University of Graz (UGR), Austria
			* new model to be developed within the project

Table 1. The SENTINEL models and consortium partners

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