Position Paper

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Norway and Europe: Securing future energy and welfare

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This position paper is a joint effort of the research centres above. They emphasize fostering collaboration between research institutions, industry, and public bodies, while also educating PhDs and postdocs who will become tomorrow's experts in green technologies. Given that the centres address research challenges of international interest, they actively collaborate with international research partners. The centres are financed by the Research Council of Norway and their respective partners.

Content

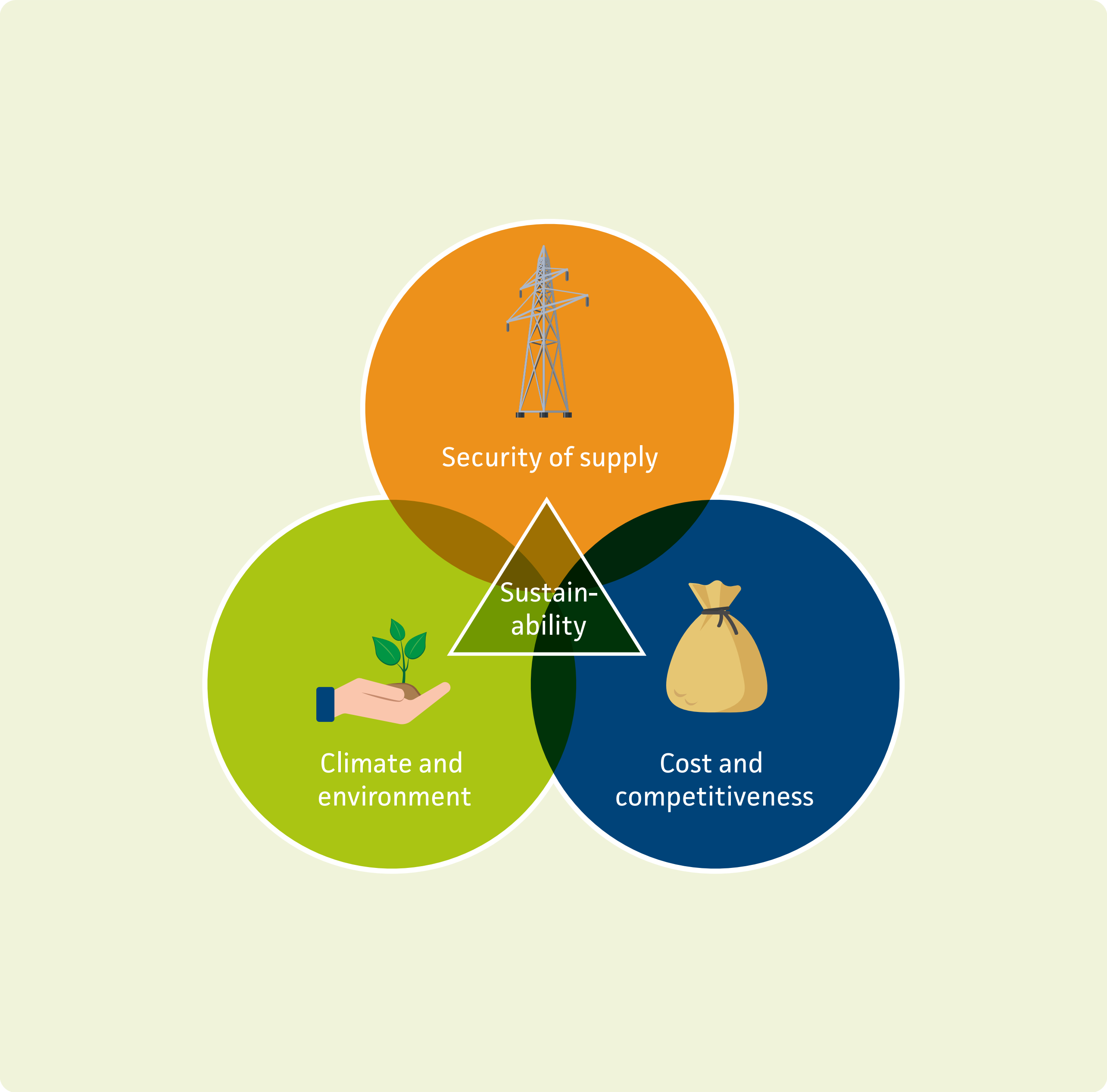


Figure 1: The energy trilemma.

Norway and Europe: Securing future energy and welfare

When Russian gas deliveries were cut off to Europe, a significant energy crisis was triggered across the continent. With skyrocketing prices and a strained energy supply, Europe was forced to hastily seek alternative energy sources. This crisis underscores the importance of security of energy supply and the challenges faced by both Europe and Norway in a changing global energy landscape. The focus has shifted in the landscape between security of supply, sustainability, affordability and competitiveness (the energy trilemma, see Figure 1).

Security of supplies in Europe have been reinstated by massive build out of LNG receiving terminals and boosting piped gas deliveries from neighboring regions and countries like Norway. Norway is now by far the largest pipeline gas supplier to Europe. Energy efficiency improvements and energy sufficiency measures together with increased renewable power production has also helped. This comes at a cost though, and competitiveness is now of great concern in the EU as higher energy prices have caused unrest and challenging market prospects for European energy intensive goods and services. The targets for climate neutrality and a suggested target of 90% CO_2 reductions by 2040 complete the picture of a multifaceted problem calling for new policies. We note with interest that the leaked draft priorities for the next strategy period for EU has three overall targets, none highlighting climate specifically, namely: A secure Europe, A competitive Europe and a democratic and fair Europe.

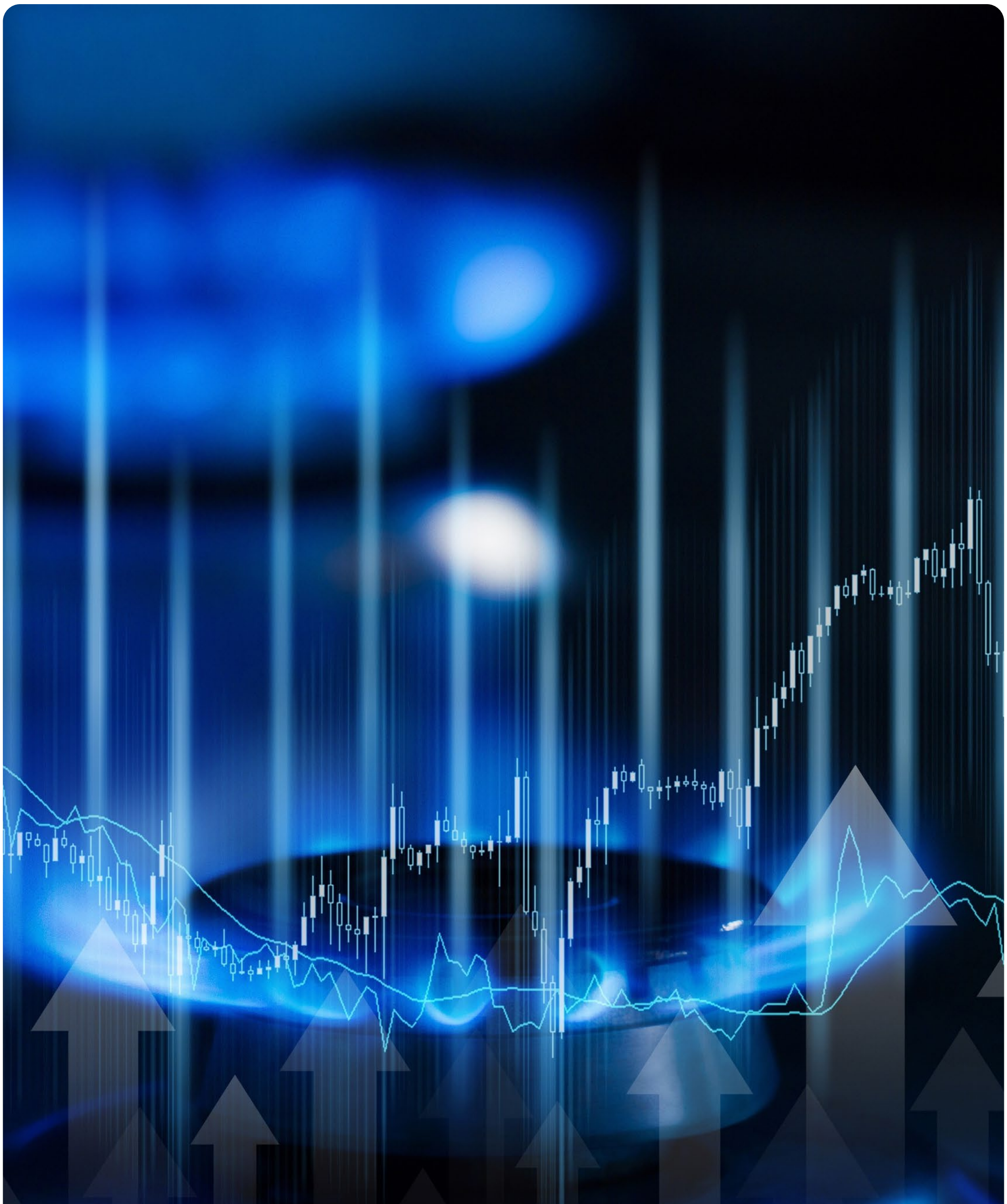
Norway, with its significant role as an energy and flexibility provider, especially in the gas market and through hydropower, finds itself in a unique situation. Norway must navigate a complex balance between securing its own energy supply and maintaining its role as a reliable energy supplier to Europe. Natural gas was Norway's largest export product in 2023, with 95% of this export directed towards Europe in pipelines. Now, Norway faces the question of how to adapt to a continent aiming for climate neutrality by 2050.

This white paper explores and discusses both Norway's and Europe's security of energy supply and Norway's role in this context. By analyzing threats to security of supply, such as conflicts, cyber-attacks, extreme weather, and other factors, we will discuss the complexity and importance of this subject. Furthermore, we will delve into the discussion of the transition from fossil to renewable energy and examine how Norway can adjust its energy strategy to meet future needs while maintaining its position as a central energy provider. This is important to maintain European welfare and competitiveness. It is also important for Norway, as an important source of income through energy export and from the fact that also Norwegian industry depends on a well-functioning European economy, given that around 70% of Norwegian mainland exports go to Europe.

Through detailed analyses and reviews of current strategies and technologies, we will provide a comprehensive picture of today's energy landscape and future opportunities. This document is intended to inform, guide, and inspire policymakers, business leaders, and decision-makers in their work to shape a more secure and sustainable energy future for Norway and Europe.

1

EXECUTIVE SUMMARY



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Executive summary

Energy is crucial for modern societies and historically linked to GDP growth. Recently, Europe and the US have seen a slight decoupling of this trend. Achieving climate targets requires zero-emission solutions, improved efficiency, and reduced energy use. We must increase renewable energy production, together with efforts for energy efficiency and infrastructure development. Efficient energy transport and storage are essential, demanding a more interconnected energy system. How we use energy, whether directly through decarbonized processes, or by leveraging household flexibility, matters greatly.

This net-zero system must be fair and respect nature, balancing climate, biodiversity, and land use. However, de-globalization poses challenges, disrupting supply chains vital for the green transition. Additionally, geopolitical unrest threatens the democratic framework we rely on, adding complexity to the energy trilemma. Norway is a small country in Europe but an energy champion for Europe. How can we maintain this role under the changing boundary conditions we have experienced the last 5 years? In this paper, we discuss the key elements of this complex situation and synthesize clear, research-based advice to ensure Norway remains a relevant energy champion in Europe.

Investments in clean energy production and energy efficiency in Norway must be boosted. In line with the ambitions of COP28, clean energy investments should triple, and energy efficiency efforts should double. Norway's onshore electricity production is nearly 100% renewable, but primary energy is only about 55 % renewable[1]. To decarbonize transport, offshore installations, and industrial processes, we need to shift from fossil-based solutions to zero-emission energy solutions.

As an energy champion, Norway also has opportunities to onshore and reshore industrial activities (i.e. bring back industrial activities) during the transition to a zero-emission society. We should save as much energy as possible and ensure efficient use of the energy we consume.

Ensure taxpayers' money is used optimally by linking R&I actions to public investments, such as the National Transport Plan, large-scale offshore wind deployment, and public infrastructure projects. Allocating 2% of these investments to R&I can help achieve optimal solutions for climate, biodiversity, and land/sea use. Both the EU and its member states, such as the Netherlands with their large-scale wind deployment, are already implementing such schemes.

To ensure the success of CCS and hydrogen, after decades of false starts, we must focus on hard-to-abate emissions. NTNU and SINTEF's advice over many years has been to establish strong R&I activities, collaborate with other countries, and engage with our main energy trade partners at the highest political levels to synchronize supply and demand. While some progress has been made, the feedback mechanism is still lacking. Effective R&I can support bilateral and multinational agreements, leveraging CCS and hydrogen as key drivers for international collaboration, clean energy export, and carbon dioxide removal.

The electricity grid will be the backbone of our energy systems in the future, not only in Norway but on a global scale. Massive investments in grids are needed for connecting the vast amounts of renewable power production, new electricity consumption in industry, transport and other sectors, and different energy storages. According to DNV, globally the grid capacity will grow by a factor of 2.5, with annual expenditure on grids more than doubling through to 2050, reaching USD 970bn. In Europe only (EU27+Norway), 67-billion-euro investment annually is needed to 2050, while new innovative grid strategies may reduce this by 12 billion euros per year. We must ensure that we optimize the utilization of the grid capacity. By modernizing the grids employing digitalization and new technologies and making use of the flexibility resources inherent in power production, consumption and storage, it is possible to increase the grid capacity by 20–25 %. The electrification and increased utilization of the grids challenges the security of energy supply as the components and grids are run closer to their limits. At the same time the grids are more exposed to natural disasters in the future due to climate change and increased weather-related stress, and the security of supply is challenged by new and increasing threats and vulnerabilities. Research and innovation are needed to understand the new risk picture, get control of the risk and find new ways of handling the security of supply for the future.

Main Message

> Our main message is to stop reducing public investments in environmetally friendly energy research.

Over the past three years, these investments have dropped by 13%, and when adjusted for inflation, by about 25%. Currently, Norway is investing only around 700 million NOK per year in research on critical zero-emission energy solutions. As a result, excellent R&I projects in energy efficiency, batteries, wind, solar, hydrogen, and CCS are not being funded. We propose increasing the investment to 1 billion NOK per year by 2025 to significantly impact our energy system and emissions, with a further doubling of this amount over the following three years. The Parliament should establish a new ”klimaforlik” for R&I, similar to the successful initiative in 2008.

In addition, we propose the following six recommendations:

1. Make the grid smarter by digitalization and automation of the grid. Extensive digitalization and automation are needed to get information about the system state and enable effective grid management and control.
2. Increase existing grid capacity by managing risk. It might be possible to increase the hosting grid capacity further if we would be willing to take a higher risk. This need to be discussed and researched further.
3. Promote local solutions, remove bottlenecks, and utilize flexibility resources. Better local coordination of demand and supply will enhance grid utilization, save on investments, and enable new connections for end users in areas where the grid would otherwise be constrained.
4. Increase renewable energy production, together with efforts for energy efficiency and infrastructure development.
5. Achieve zero emissions in natural gas value chains by 2050 and in new field developments by 2040. These value chains are crucial for European security of supply and for meeting European climate goals.
6. Strengthen European cooperation on large-scale infrastructures for CCS, hydrogen, and the offshore grid.

2

SECURITY OF ENERGY SUPPLY IN NORWAY

Security of energy supply in Norway

2.1 What is the security of energy supply?

Society is highly dependent on a secure electricity supply which is increasingly important in the energy transition as more sectors are being electrified to substitute fossil fuels, such as in industry and transport. The electricity grid facilitates the integration of other energy carriers and forms of energy storage. According to the European vision 2050[2], the energy system will be fully integrated by 2050 with the electricity grid as the backbone. Through the integration of energy systems and coupling of various sectors, the security of supply of the different energy vectors will affect each other in new ways.

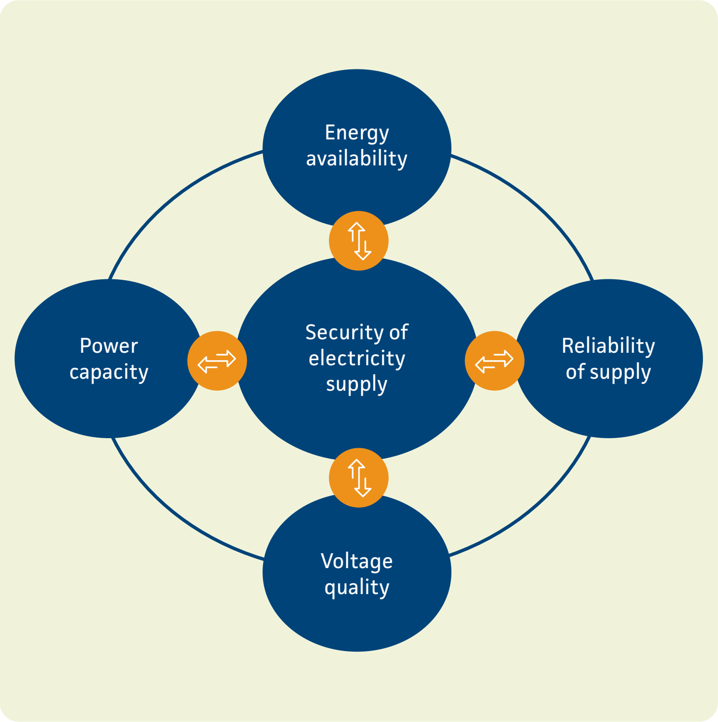

Figure 2: Security of electricity supply.

Security of supply means the ability of the energy system to supply end-users with energy of a certain quality on a continuous basis[3,4]. The security of supply is composed of four main elements, as illustrated in Figure 2 (here for electricity[4]):

- *Energy availability (also termed as 'energy security'):* the ability of the power system to cover the energy use. Energy shortage is characterized by reduced availability of primary energy resources to produce electricity
- *Power capacity:* the ability of the power system to cover the instantaneous demand, characterized by available capacity in power generation and power grids
- *Voltage quality:* the quality of the supply voltage at the end-user
- *Reliability of supply:* the ability of the power system to supply electricity to the end-users, related to frequency and duration of power supply interruptions.

The operational reliability, defined as the ability of the power system to withstand sudden disturbances such as short circuits or non-anticipated loss of system components without causing interruptions to end-users, as well as cyber security are also parts of security of electricity supply. The security of electricity supply (SoS) is also affected by interactions between the different elements of SoS described above. In Norway, the SoS is high, illustrated by a reliability of supply of around 99.98 %. This means that end-users experience power interruptions 2-3 hours per year on average.

The definition of security of electricity supply presented above is specific to electricity/electric power. However, it may be generalized for other energy vectors such as heating, cooling and gas. A more general definition of security of energy supply (SoS) would be the ability of the energy system to supply end-users with energy of a certain quality on a continuous basis. The elements can be provided simply by substituting the terms electricity, electric power or power supply, with the terms energy and energy supply. The exception is the quality-element which will be quite different for the various energy vectors, related to the technical properties of the energy carriers (e.g., temperature and pressure instead of voltage- and frequency-related measures as in the electric power system).

The energy availability or energy security is measured in terms of the energy balance year by year (see e.g. NVE 2023[5]), while the power capacity is typically measured by the system's ability to cover the (hourly) maximum power in a year. In Norway, the energy and power balance for electric power are getting strained, approaching shortage towards 2030. The reliability of supply is determined by failures and disturbances in the energy system leading to component outages and supply interruptions to end-users. The national reporting system FASIT is used for collecting information on component failures and power supply interruptions in the electric power system.

2.2 Norwegian energy scenarios and the growth in electricity demand

The availability of energy to cover our national consumption is central to any discussion on energy security in Norway. This issue is linked to several democratic choices on how the Norwegian society will and should evolve over the next decades. This connection becomes clear when considering several recent reports. The energy commission (NOU 2023:3[6]) was asked by the government to map the energy needs and the need for new energy generation based on the underlying objective that Norway should have a power surplus and that ample supply of renewables should be a competitive advantage for Norwegian industry. The NOU points to massive needs for new renewable power generation by 2030 (40 TWh) and increased energy efficiency (saving 20 TWh) in Norway by 2020. In 2030, the expected growth in energy use is between 21 TWh and 35 TWh. Statnett´s report "Forbruksutvikling 2022-2050"[7] shows a range from 190 -300 TWh power consumption in 2050. Common to both of these is that they recognize the massive needs for energy efficiency, but at the same time, they assume that electrification and increased activities in society will lead to increased power consumption. This aligns well with today's industrial structure in Norway and continued growth in these sectors.

Furthermore, the above-mentioned NOU 2023:3 points to the need for change and argues that existing emissions need to be removed or dramatically reduced by reducing activity, changing behavior and use of zero emission technologies. This report argues that strong instruments to promote energy efficiency should be introduced and that renewable generation needs to increase to replace fossil energy, but also argues that low energy prices should not be a main objective for the energy policy. Energy prices should reflect the cost of new power generation.

In this chapter, we illustrate through four transition scenarios provided by the Norwegian Centre for Energy Transition Strategies (FME NTRANS) some of the choices we have as a society and how they affect the Norwegian society´s need for electricity.

2.2.1 The four NTRANS scenarios

The research centre NTRANS has developed four contrasting scenarios for the Norwegian energy transition towards 2050. The four socio-technical scenarios describe different pathways based on the level of disruption, measured across societal change (system architecture change) and technological change. The pathways are:

1. **Incremental Innovation Pathway (INC):** Involves minimal disruption, focusing on small improvements that are the least challenging.
2. **Technological Change Pathway (TECH):** Deploys new core technologies while retaining the existing system architecture, aiming to integrate them with current incumbent actors.

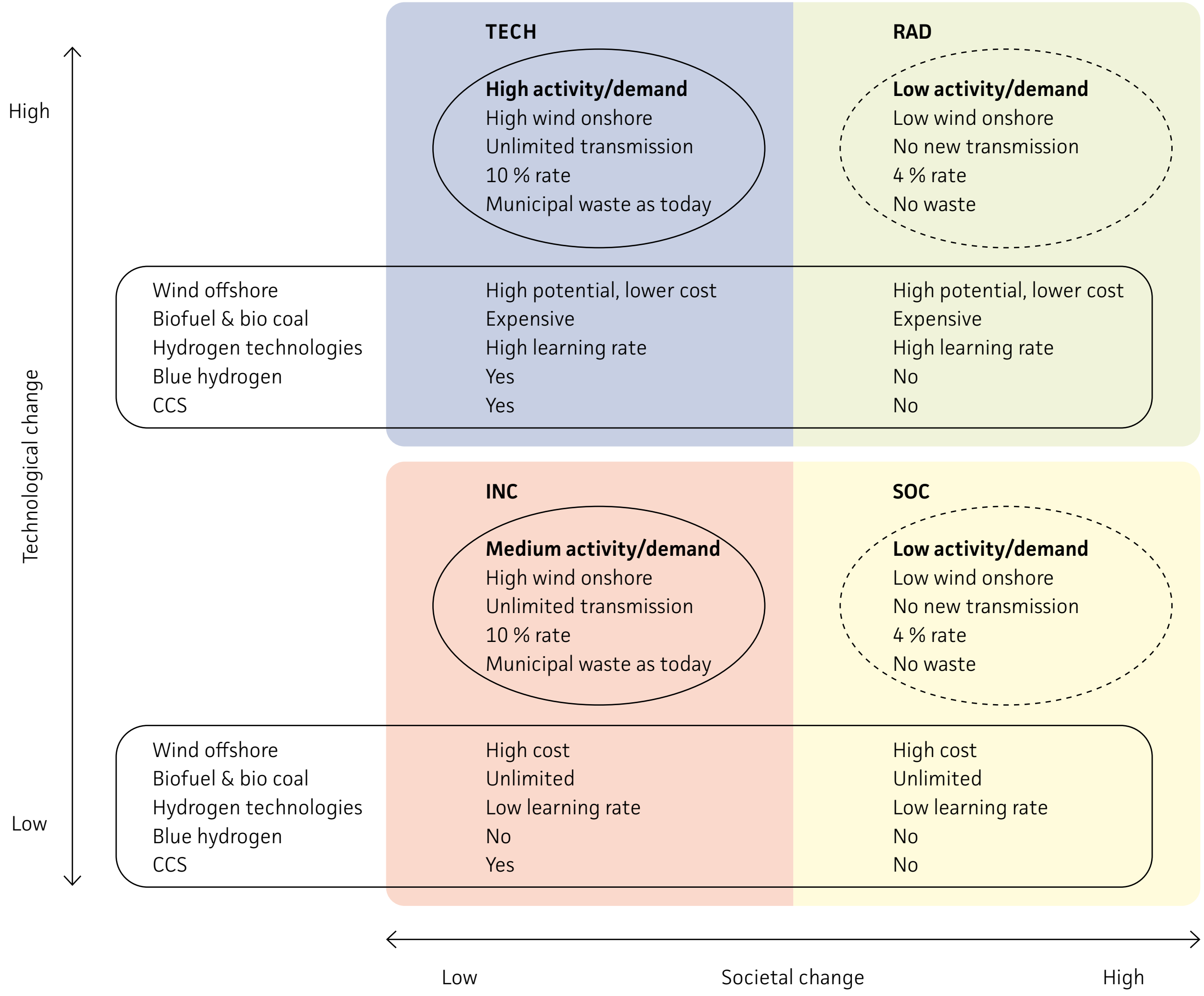

Figure 3: Main differences between the four scenarios for the Norwegian energy transition towards 2050 as provided by the NTRANS research centre.

3. **Social Change Pathway (SOC):** Focuses on significant socio-institutional and architectural changes, prioritizing new system functionalities and services with minimal changes to core technologies.
4. **Radical Transformation Pathway (RAD):** The most disruptive, involving a comprehensive transformation of system architecture and institutions to accommodate new technologies at both core and architectural levels.

These pathways are described in more detail in the NTRANS report "NTRANS Socio-technical pathways and scenario analysis"[8]. Figure 3 stems from the report and summarizes some main differences. In the next sections, we will describe briefly how power demand, and power supply develop under the scenarios.

2.2.2 Power supply in the NTRANS scenarios

The TECH scenario is the most expansive scenario, projecting 380 TWh power production by 2050, while the INC scenario projects just over 250 TWh (see Figure 4). In the RAD and SOC scenarios energy demand is lower and the analyses suggest an increase in power production with 30 TWh and 38 TWh by 2050 compared to the current situation. In all scenarios, onshore wind is preferred and reaches its fixed upper limit of 48TWh in the INC and TECH scenario. In SOC and RAD, new production is mainly supplied by building-applied PV (BAPV), with only reinvestments in existing wind capacity. In the TECH scenario, offshore wind is the main supplier with 164 TWh, corresponding to 43 % of the total generation, exceeding that of hydropower at (41 %). From an energy security perspective, it is worth noting that the TECH and INC scenarios indicate a supply around 200 TWh in 2030, indicating an ambition above today's pace in investments in renewables.

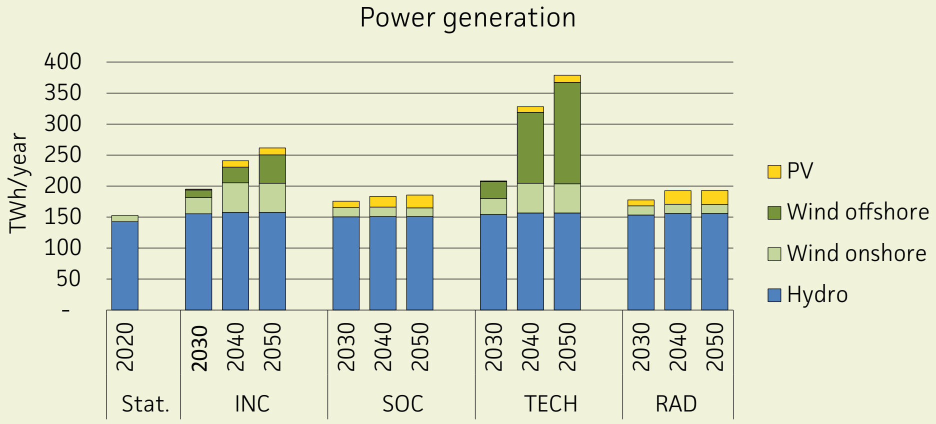

Figure 4: Power generation in different NTRANS scenarios for the Norwegian energy transition towards 2050.

2.2.3 The power system balance in the NTRANS scenarios

In the SOC and RAD scenarios, no new transmission cables are allowed, and only radial connections to Norway are permitted. In contrast, the INC and TECH scenarios can benefit from hybrid cables, making offshore wind a more profitable solution. The INC and TECH scenarios, as a consequence, have large power export volumes. It is worth noting that all scenarios have a positive electricity balance in 2030, while NVE estimates the balance to be around zero with current actions[5]. Hence, all four NTRANS scenarios aim for higher energy security than what we see in current plans (see Figure 5).

2.2.4 Power demand from the NTRANS scenarios

The electricity use in buildings decline in all scenarios (see Figure 6) because of increased use of district heat and bio energy boilers, as well as more efficient heating due to increased use of efficient heat pumps and less use of direct electric heating and electric boilers. In SOC and RAD scenarios, 15 TWh of energy efficiency measures are implemented. The electricity use in industry increases in the INC and TECH scenarios due to a higher activity level in industry in these two scenarios. Electricity use increase by 70 TWh in the TECH scenario by 2050 while the INC has an increase of 40 TWh. The SOC and RAD scenarios have a minor decrease in electricity use in industry, 2 TWh, mainly due to the phase-out of the O&G industry.

Large volumes of green hydrogen production occur in the TECH and RAD scenarios. It is worth noting that in the SOC and RAD scenarios the combined electricity use in buildings and industry is around current levels in 2030, but

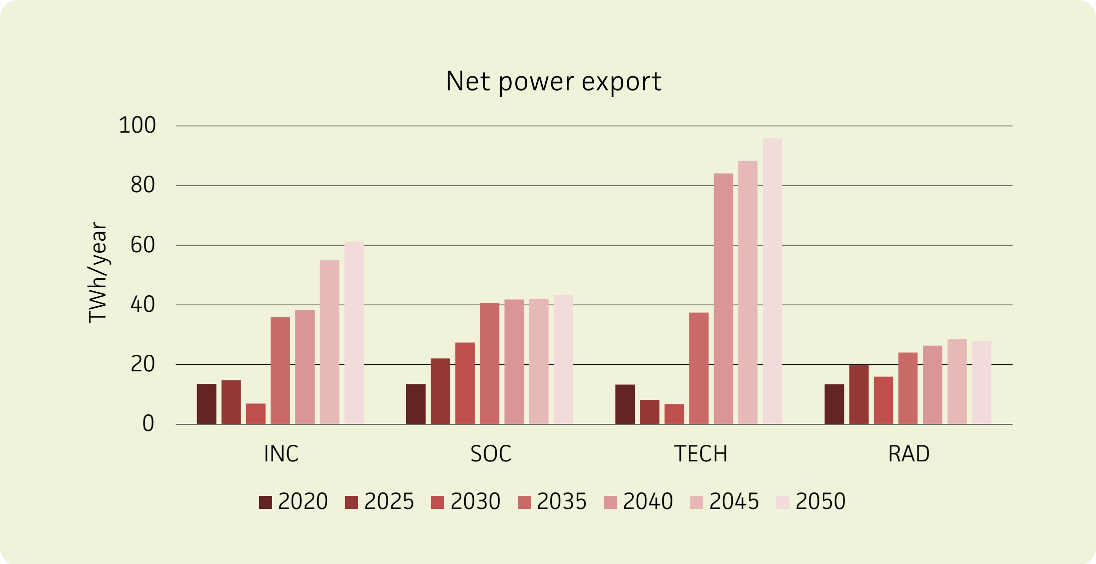

Figure 5: Net power export in the different NTRANS scenarios for the Norwegian energy transition towards 2050.

then decreases towards 2050. This is not in line with a policy where reduced activity in the oil and gas sector will be compensated for with industrial activity using clean electricity.

The analysis also investigates the impact on economic development, and for the two scenarios with high societal change (SOC and RAD), a lower GDP development, and lower value added from both the industry and service sector is presented.

2.3 Energy efficiency

Energy efficiency is essential both to meet climate objectives and in order to increase energy security. In addition, flexibility from buildings and energy societies are key.

Buildings account for around 40% of energy consumption in Europe. In the transition to smart grids, end-users play an increasingly important role in the energy system, also generating distributed energy and providing end-user flexibility.

There is a considerable energy efficiency potential in the Norwegian building stock. ZEN report no. 50[10] used the RE-BUILDS model to estimate the potential for energy efficiency in the Norwegian building stock towards 2050 in two scenarios: Baseline and Ultra green.

The Baseline scenario assumes that further development still follows current trends for energy levels in new and renovated buildings. The Baseline scenario shows that a continuation of the current trends leads to total added energy increasing by 2 TWh from 2020 to 2030 and by 4 TWh from 2020 to 2050. The increase is because the building stock is

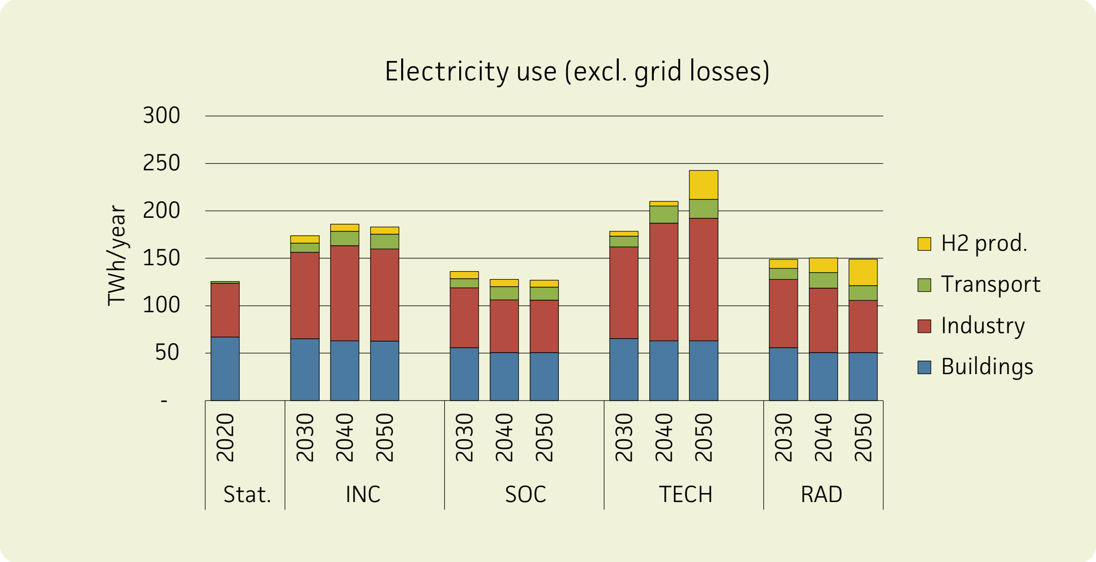

Figure 6: Electricity use in the different NTRANS scenarios for the Norwegian energy transition towards 2050.

growing, and the improvement in energy levels cannot fully compensate for this increase.

The Ultra Green scenario looks at what is a realistic potential for energy efficiency, with very ambitious upgrading of energy efficiency levels for new buildings and renovation, conversion to the most energy efficient heating technology and use of solar cells on buildings. The Ultra Green scenario shows that total delivered energy is reduced by 13 TWh (15%) from 2020 to 2030 and by 40 TWh (48%) from 2020 to 2050. In the same periods, purchased electricity is reduced by 13 TWh (19%) and 42 TWh (60%). This reduction results from ambitious measures that significantly improve the average energy level, use the best available heating technology, reduce in electricity-specific energy demand and maximize the use of solar electricity. Solar electricity production is 4 TWh in 2030 and 12.5 TWh in 2050. The scenario assumes optimal use of smart control systems so that in 2050, 10 TWh of solar electricity is for own use and 2.5 TWh is exported to the grid (calculated on an hourly basis).

To unleash the potential in the Ultra Green scenario, we estimate a need for financial support of 4-5 billion NOK per year. The amount of support could be reduced if solutions and technology improve and become more cost-effective. The estimated need for financial support is significantly more than today's level. Untapping the potential for energy efficiency in the building stock should be assessed against the alternatives we have to solve the climate targets and to avoid the energy deficit we are heading towards. Investments in building energy efficiency measurements results in new jobs across Norway, where people live, by development of new building technologies and upgrading existing buildings.

2.4 Industrial energy use and value creation

Security of energy supply is important for national and international value creation through the utilization of energy for production of necessary and valuable products. For such production, it is an important perspective that energy as a scarce resource is used as efficient as possible. In addition, the losses from industrial production, mainly through excess heat not utilized in the internal processes, must be utilized for other purposes in the integrated energy system of the future. The European energy consumption is approximately 10300 TWh, of which 1000 TWh is lost/not utilized surplus heat. This is comparable to the Norwegian situation where at least 20 TWh of surplus heat from Norwegian industry is not utilized, which is approximately 10 % of the land-based energy consumption. Further to this, bearing in mind that 50 % of all energy consumption is used for heating and cooling purposes, utilization of the surplus heat will reduce the consumption of electricity, which then can be more efficiently utilized for other more efficient purposes.

For new industries, such as battery factories, H_2 production, data centres and CCS, the utilization of heat is an important aspect. Data centers use electricity for data processing, where more or less all the electricity is converted to low-grade heat. Battery factories need low-temperature heat for drying purposes, CCS requires process heat for the CO_2-absorption/desorption process etc. New industries will affect the energy system and impact the prioritization of energy consumption with the risk to energy security. As such, utilizing energy as efficiently as possible will give room for new industries, but also the utilization of surplus energy will contribute to increased energy security in the integrated energy system of the future.

2.5 Energy system integration

Reduced energy delivered to buildings, together with increased use of district heating, has a great potential to reduce Norwegian electricity demand and at the same time contribute to increased energy system flexibility when the grid is under the highest load. Cold periods in the winter and the use of direct electric heating in Norway have been some of the driving forces for investments in the power system. The increased need for more power production and grid capacity can be partially avoided with a strong emphasis on buildings' energy efficiency, together with the use of district heating in urban areas and heat pumps in rural areas. Energy system integration can result in more efficient utilization of the total energy resources and contribute to less land use and intervention of the natural environment related to building new infrastructure.

ZEN report no. 47[11] quantified the potential for increased use of district heating and heat pumps on reducing buildings' future electricity demand in Norway. The study shows that increased use of district heating reduces buildings' electricity consumption, and particularly the buildings' peak power demand. A net reduction in both total electricity and peak power demand in buildings is achieved only when maximal use of district heating is combined with ambitious energy efficiency standards and maximizing the use of heat pumps in rural areas where district heating is not feasible. This scenario allowed a reduction of -12% in buildings' electricity demand by 2030 and -26% by 2050, compared to 2020 levels. The buildings' peak power demand could be reduced with -17% by 2030 and -35% by 2050.

Utilization of the excess heat available from industries that are geographically located in the vicinity of rural areas for district heating purposes will further increase society's efficient use of energy. This energy is already available, as mentioned in section 2.4.

2.6 Electrification and the future power grid

The power system is gradually transformed from today's centralised system, where large power plants follow the load, to a decentralised system, where the load follows the generation to a much higher degree. According to the ETIP SNET Vision 2050[12], the energy system is fully integrated in 2050, with the electricity system as the backbone, the customer is fully engaged, and digitalisation is everywhere.

Electrification is highlighted as one of the most important means to reduce the CO_2-emissions, nationally (see Klimakur 2030[13]) and internationally (see IEA Electrification[14], and IEA Net Zero Roadmap 2023[15]), providing more than 30 % of the potential emission reductions. For Norway with a total energy consumption of 315 TWh in 2022 (of which 240-250 TWh is land based) and 135-140 TWh based on renewable electricity, this represents a significant challenge for the future. The power grid is thus a crucial enabler for the energy transition.

Electrification, integration of variable renewable energy sources at end-user level, and the increase in new power-intensive industrial loads such as data centres, battery factories, hydrogen production and fast-charging stations, impose new challenges to distribution and transmission grid operators due to changes in production and consumption patterns and more strained operating conditions. The electrification goals pose an urgent need for increased power production as well as more power transmission and distribution capacity. Norwegian grid companies and the national system operator Statnett receive regular electrification enquiries. In various parts of Norway[16], the grid has no spare capacity, and many requests for new grid connections for the establishment of new industry and other businesses are denied. This reduces the possibilities for value creation and CO_2-emission reductions.

The Centre for Intelligent Electricity Distribution (FME CINELDI) works towards digitalization and modernization of the electricity distribution grid with the main objective of being an enabler and facilitator for a cost-effective realization of the future flexible and robust power distribution grid. The scope of CINELDI covers the power grid from the regional to the local grid levels. In addition, CINELDI covers the interaction between the distribution grid operators (DSOs) and the transmission system operator (TSO). A flexible, intelligent, and robust distribution grid is a key enabler to achieve energy and climate goals related to increased distributed generation from renewable energy resources (solar, wind and hydro), electrification of transport and other sectors, and a more flexible power and energy use. The transformation to the future flexible, intelligent, and robust grid should be made with acceptable costs, without jeopardizing the security of electricity supply.

Providing electricity with a high security of supply, which is also affordable, while at the same time ensuring the environmental goals, is often termed the energy trilemma (also see Figure 1), as these three goals are partly contradicting. In the energy trilemma, the aim is to find an optimal balance between these three.

2.7 Factors that may affect security of energy supply

Many factors can affect the security of energy supply (SoS). The energy systems are changing due to the transition to the low-emission society, substituting fossil fuels with renewables, energy system integration, sector coupling, electrification and digitalization, etc. These aspects may negatively impact SoS in different ways, but they also offer opportunities for new approaches to managing SoS in the future. On the other hand, complexity, uncertainty, and unpredictability are increasing due to interdependencies and more variability. As mentioned above, the energy system will be more exposed to natural disasters in the future due to climate change and increased weather-related stress, and the SoS is challenged by new and increasing threats and vulnerabilities.

To study and identify the factors affecting SoS, it is useful to look at the unwanted events related to the SoS elements, and the risks and vulnerabilities, based on the bow tie-model as illustrated in Figure 7.

The main unwanted events which can threaten the security of supply are energy shortages, capacity shortages or component outages, or combinations of these[17]. Shortages may cause extremely high prices or curtailment/ rationing, while failures and outages can cause wide-area supply interruptions (blackouts) and major harm to society. There are interactions between the different elements of security of supply that need to be considered, e.g., energy and capacity shortage, or situations where components are out for maintenance or other causes, may give rise to strained power situations increasing the probability of wide-area interruptions.

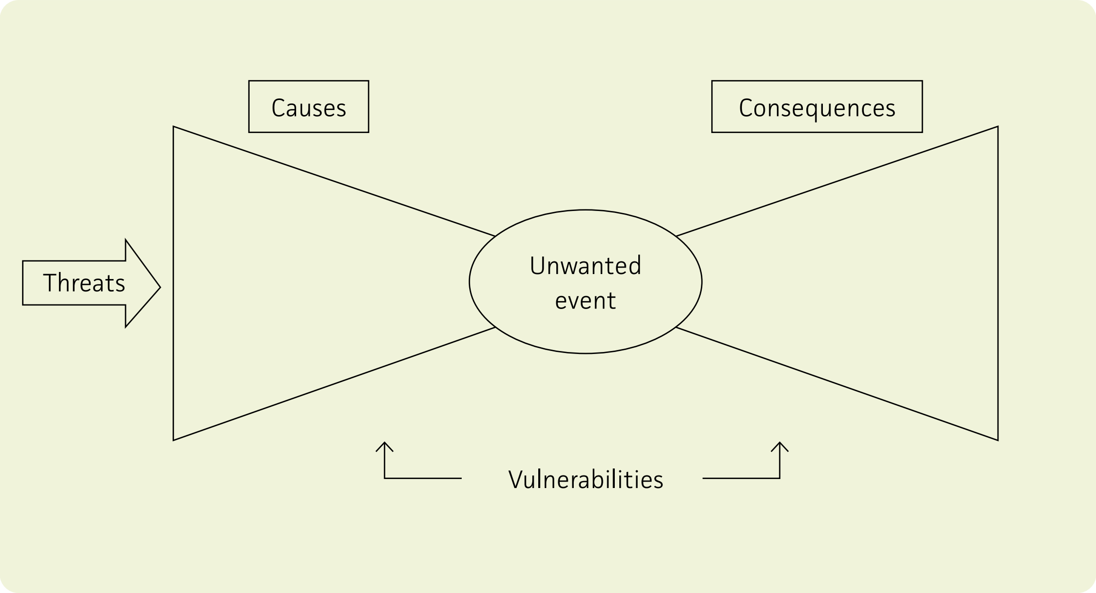

Figure 7: The bow tie model describing the relations between causes and consequences of unwanted events.

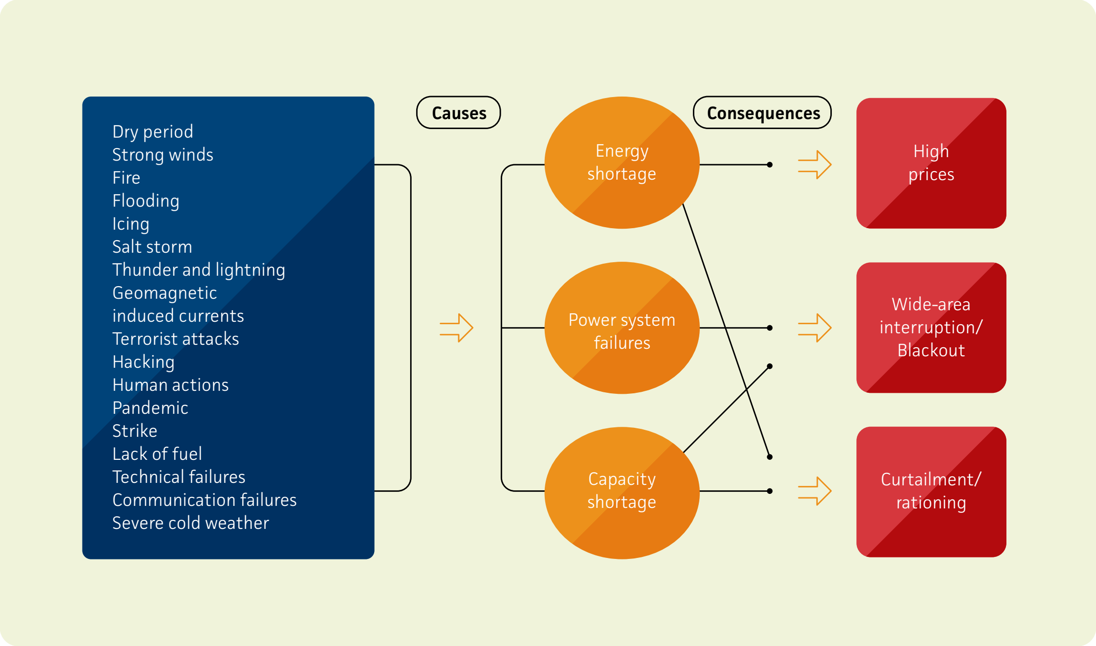

Figure 8: Threats leading to unwanted events and different consequences.

This shows that the security of supply should be considered holistically.

The relationships are illustrated for power systems in Figure 8, for unwanted events and different consequences on a pan-Nordic level. The possible consequences of the unwanted events are shown to the right in the figure, while the threats are shown to the left.

The consequences are explained as follows:

- “Blackout” situations refer to extensive component outages, involving supply interruptions for large geographical areas and/or many people. A blackout is related to unplanned outages of power components or a capacity shortage. An energy shortage situation may change the probability of a blackout but does not in itself cause a blackout. It can however lead to curtailment (see below).
- “High price” indicates incidents where the spot price is significantly higher than the normal level for a sustained period. Such situations are mainly related to energy shortage.
- “Curtailment” refers to situations where a controlled rationing or load curtailment is affected. Curtailment may occur in the long run caused by energy shortage or in the short run caused by capacity shortage.

Analyses of historic blackouts show that their causes often are on the system or organizational level, representing a combination of factors, for example:

- Strong winds and treefall (common causes) resulting in extensive damage to infrastructure.
- Malfunction of critical equipment such as line protection and cable joints or sleeves.
- Strained operating situations where the system is operated close to its limits
- Human factors – lack of situational awareness and lack of coordination and planning of activities that may have an impact on the system (for example digging work, etc.).

The threats (to the left in the bow tie) are external to the energy system. They may be grouped into categories such as natural hazards (e.g. extreme weather), operational/technical (e.g. loading conditions), and human (errors or antagonistic).

Vulnerabilities are composed of susceptibility to threats and (lack of) coping capacity, which are internal characteristics of the system. Vulnerability influencing factors may be divided in technical, organizational and human factors exemplified as follows:

	Susceptibility	Coping capacity
Technical	Technical condition of components Operational limits Redundancies	Equipment for repair Availability of spare parts Reserve/alternative solutions
Organizational	Availability of information Coordination between relevant actors Market design inadequacy	Availability of communication Coordination of restoration and repair Contingency plans
Human	Availability of skilled personnel Operative competence Human errors	Availability of personnel Competence and skill in system restoration and repair of critical components

To identify how the SoS and its various elements are affected, it is important to understand the new risk picture and how the changes in the energy system and the surroundings lead to changes in threats, vulnerabilities and consequences.

2.8 Better utilization of the power grid and security of supply

Both transmission grids and distribution grids play a central role in providing security of supply. The power grid connects power generation with power consumption, and the ability to move energy from where it is generated to where it is used is key for resource utilization. With increased variability and intermittency in the power supply due to renewables like wind and solar, the grid also is a key to handling variations, because most often the variability is not perfectly correlated between geographic locations. The grid enables system operators to transport energy from areas with high generation to areas with low generation, and to balance the system.

The role of the power grids will change in the years to come due to increased electrification, sector coupling, energy system integration and interplay with new actors, such as flexibility providers and Local Energy Communities (LECs). More variable and intermittent power production increases the need for flexibility[18] to balance production and consumption. The transition to the cyber-physical flexible and intelligent power grid introduces new types of components, new operating patterns and increased complexity, new types of threats (cyber-) and vulnerabilities, leading to a changed risk picture related to the security of energy supply. At the same time, the power system will be more exposed to natural disasters in the future due to climate change and increased weather-related stress. The new risk picture must be understood to find the right strategies for dealing with the security of supply in the future power system.

The current level of security of electricity supply is high (99.98 %), however, it is challenged by new and increasing threats and vulnerabilities:

- Natural hazards, extreme weather due to climate change
- Cyber threats and interdependencies due to intensified digitalisation and system integration
- Operational stress due to changed and more strained operation patterns (higher share of new intermittent renewables, electrification, energy system integration, etc.)

One of the main challenges is to reduce the effects of or remove bottlenecks in the grid. Such bottlenecks have several negative effects. First, when the ability to transport energy between geographic locations is fully utilized, price differences between the areas develop with higher prices linked to higher demand and/or lower generation. Second, when a line is congested it cannot be used to resolve security of supply issues such as to support the N-1[19] criterion. Third, in areas where the system operators consider that there is a high chance of capacity problems, new connections for high demand end-users may be limited as described above. Hence, lack of grid capacity may in the worst-case lead to a slower pace in electrification of sectors that today emit CO_2, like process industry and transport.

The needs for increased hosting grid capacity due to the vast amounts of requests for connecting power production and new power-intensive loads must be met through new grid investments. However, investments can partly be reduced and deferred through a more efficient utilisation of the existing grid[20]. A better utilisation enables faster grid connections and increased value creation. This will also reduce the grid costs as well as the need for land-use and nature interventions.

Here we will describe three ways to achieve better utilization of the grid: Digitalization and smarter grid management; risk-based grid management; local solutions and flexibility. All of these can be used for handling security of supply and to increase the hosting capacity.

Make the grid smarter by digitalization and automation of the grid

Digitalization and automation of the power grid comprise various technologies and solutions for monitoring and control of the grid, such as utilization of sensors, intelligent components, communication systems and automatic regulation systems. Extensive digitalization and automation are needed to get information about the system state and enable improved grid management and control. Examples of technologies and solutions include utilisation of sensors to provide dynamic capacity limits[21, 22], transformer on-load-tap-changers (OLTC[23]) and solutions for self-healing grids[24]. These are examples of active grid measures for increased hosting capacity. Some grid companies' have stated ambitions of 20-25 % increased capacity by combining such active grid measures with utilisation of flexibility[25].

The available hosting grid capacity is based on technical limits to prevent voltage violations, disturbances and supply interruptions. Due to the limited information available on the system operating state today, these are conservative and static limits. Grid monitoring and decision support make dynamic limits possible as confirmed by research and pilot projects in CINELDI.

Increase existing grid capacity by managing risk

What may be considered as available grid capacity is also based on what is regarded technically feasible related to the N-1 criterion. The current practice is to operate the grid according to this criterion according to which the power system should be able to withstand a failure of a component without interrupting power supply to end-users. The N-1 criterion implies that there are reserves available in case of a single failure. On the local distribution grid levels, N-1 can partly be met using reserve connections, restoring the supply after a failure. However, N-1 does not consider the probability or consequences of failures and disruptions.

In the NOU-report "Mer av alt – raskere"[26], it was discussed if the grid companies could be willing to take a higher risk and increase the hosting capacity by deviating from the N-1[27]. The European research project GARPUR developed probabilistic reliability criteria, and it was shown that this would provide a better balance between reliability of supply and socio-economic costs. Using probabilistic criteria enables risk-based planning and operation, and would allow the power grids to run closer to their limits. Thus, it might be possible to increase the hosting grid capacity further if we would be willing to take a higher risk. There may also be situations where we would need to reduce the risk. This need to be discussed and researched further. This is a topic of research in the new research centre FME SecurEL that will start in 2025.

Promote local solutions, remove bottlenecks, and utilize flexibility resources

Flexibility is defined as the ability and willingness to modify generation injection and/or consumption patterns, on an individual or aggregated level, often in reaction to an external signal, to provide a service within the energy system or maintain stable grid operation[28]. Flexibility resources are flexible power production (e.g., hydro- or solar power), consumption (e.g., electrical water heaters and electrical vehicles), and energy storages (e.g., batteries, thermal storage[29]).

The grid customer may regulate their own consumption or production manually or automatically or may have an agreement with the grid company or a third-party. Local energy communities (LEC) and microgrids consisting of several flexibility resources can also be used as flexibility resources in the power grid[30,31]. Energy use in buildings and areas, such as heating and EV charging, can be flexible in time without compromising the comfort of the end-users. Utilizing end-user flexibility, energy use can to a greater extent follow the production from renewable energy sources, particularly if there also are energy storage options integrated in the system. Energy-flexible buildings and areas can also contribute to better utilization of the capacity in the energy networks (power grid and district heating network), by shifting energy use from peak times to times with available capacity.

The project Flexbuild[32] aimed to understand how end-use flexibility could impact the future energy system in Norway, and main takeaways are available in the final report. Flexbuild found that end-use flexibility had the potential to reduce peak loads at the single building level by 20- 50%, and about around 16-20% at the aggregate level. Combining end-use flexibility with solar PV is economically advantageous from the end-user perspective, since flexibility increases self-consumption. At the same time end-use flexibility virtually eliminates the need to install batteries.

Energy societies can be organized to coordinate between end-use customers within a geographical area. This coordination may, for example, ensure that local energy consumption is aligned with energy generation from solar panels and wind turbines locally, reducing bottlenecks and improving grid utilization. This will also make it possible to reduce the peak grid capacity needed into the area.[33] New regulation needs to be implemented for this local coordination to happen efficiently, such as:

a) regulation that allows internal coordination and trading
b) a tariff scheme and/or markets that incentivize coordination, and
c) schemes that incentivize investments in local solutions
d) new regulation needs to consider that grid tariffs still should cover the cost of the grid, and do not lead to negative distribution effects between customer groups

Another solution for allowing more customers into the grids is conditional connections, where the allocated capacity is not firm. This allows flexible consumers to be connected, on the condition that when the grid is congested, they may receive reduced capacity.[34]

Even higher resource utilization may be achieved by establishing local flexibility markets where end users and power producers can sell flexibility to improve the local energy balance in such a way that energy is consumed where the value is highest[35].

- There is a need to better understand which properties of flexibility services will be in demand in the future power system.
- There is a need for more coordination across flexibility services to prevent problem-solving from creating new problems later or elsewhere. Increased prevalence of new flexibility services in the low voltage grid will increase the need for coordination between the markets, as the location aspect becomes more relevant.
- End-users should be given opportunities to offer flexibility services without compromising vulnerable and inflexible end-users.
- The development towards energy system integration will also make it possible to a larger extent to utilise other energy carriers as flexibility resources for the power grid. This requires also more integrated markets.

3

EUROPEAN ENERGY SECURITY AND COOPERATION WITH NORWAY

European energy security and cooperation with Norway

In this section we will address several of the interfaces between the Norwegian energy systems and the European energy system considering energy security and decarbonization strategies.

3.1 The role of hydropower

Hydropower, often referred to as the "forgotten giant"[36] of low-carbon electricity, plays a crucial role in global electricity generation. It currently supplies almost half of the world's low-carbon electricity, surpassing the contribution of nuclear power and all other renewables combined[37].

While hydropower's capacity has grown by 70% globally over the past two decades, its share of total generation has remained stable due to the growth of other energy sources such as wind, solar PV, coal, and natural gas.

In Norway, hydropower plays a unique role producing 88% of the electrical energy[38] in 2022 and is the pillar of the energy system. The recent Norwegian NOU-report from the Energy commission[39] emphasized the need for flexibility from hydropower, which we can get from Norway's water reservoirs that provide the opportunity to flexibly balance supply and demand for electricity. A greater influx of unregulated renewable power puts the balance in the energy market under pressure. New and innovative hydropower solutions, focusing on flexibility, can enable a faster, deeper and broader transition to a carbon-neutral energy system[40].

Hydropower technology has traditionally been developed for high efficiency and availability. By improving its flexibility, hydropower can contribute by controlling its power generation in timescales ranging from seconds to months[41]. The transition to being a flexibility provider demands well-functioning market designs to valuate and incentivize flexibility services, and careful environmental considerations, ensuring ecological status in reservoirs and environmental flows in rivers, providing suitable habitats, managing hydropeaking impacts, and implementing mitigation measures for biodiversity and ecosystem functioning. These environmental aspects are carefully balanced against the significant contribution of hydropower to flexible energy supply and security, and climate change adaptation and mitigation potential. Transforming hydropower into a flexibility provider has many positive socio-economic impacts, such as industrial developments, water supply, irrigation, and flood protection.

The available resources depend on the annual rainfall. Norway has a total hydropower storage capacity of 87 TWh, and this is about half of Europe's capacity. The reservoirs have a high degree of flexibility and production can be adjusted up and down quickly as needed, and at low costs. Total production capacity for Norwegian hydropower was 33.7 GW in 2023[42]. Norway currently has very little pumping capacity, only about 1 GW mainly used for seasonal pumping. Expectations of more volatile power prices are actualizing capacity expansions in production and pumping. A study carried out by SINTEF identified a potential for up to 18.5 GW expansion of hydropower production capacity in Norway including 9.2 GW pumping[43]. However, any capacity expansions must be assessed against the impact on local nature and environmental conditions in reservoirs and waterways.

Increasing the flexibility in hydropower production and other sources of flexibility will reduce the peak prices and thus the profitability of the investments. It is expected that the value of hydropower will increase when seen in relation to the massive amounts of offshore winds that are planned by Norway, the EU and the UK. The hydropower reservoirs make it possible to store energy for time periods with little wind. At the same time the expectations for a masked offshore grid linking together the countries around the North-sea enable the sale of this flexibility to neighbor countries. This requires that the Norwegian onshore energy system is linked to the offshore wind installations.

3.2 The role of wind

In the Norwegian onshore energy system, most model studies show that onshore wind is an attractive technology from an economic perspective. In the Norwegian scenario studies (see chapter 2) and similar analyses performed with the EMPIRE power market model, the results normally show that after hydropower, onshore wind is the preferred technology from a cost minimization perspective. From an environmental perspective and considering conflicts of interest with recreational or other cultural or economic use of the land areas, the picture is not as clear. Still our analyses (see chapter 2) show that with the ambition to increase Norwegian energy generation with tens of TWh before 2030, onshore wind may be the only realistic solution.

Most studies of the European power system estimated developments of massive amounts of offshore wind. One of the more attractive areas is the North Sea, due to its good wind conditions and central position close to high demand areas of the EU and the UK. As mentioned, the potential links to Norwegian hydropower to balance it are attractive from a security of supply perspective. In the following we will give some examples of the volumes different European studies estimate for offshore wind developments in Europe.

The EMPIRE power market model for Europe is often used for investigating cost-minimizing technology mixes for Europe towards 2050 under different assumptions. Typically, the solutions indicate between 180-270 GW of installed capacity of offshore wind in Europe, with a substantial part of it in the North Sea. See for example Durakovic et al. (2023)[44]. Here 270 GW of installed capacity would correspond to an annual expected generation of 900 TWh (more than 6 times the current Norwegian power generation). This development is supported by building massive transmission capacities in a meshed offshore grid between the North-sea countries.

The Ostend-declaration[45] points at offshore wind as a future main source of electricity. The declared goal between the North Sea countries is to install a total of 300 GW of offshore wind by 2050. This means that over the next 25 years, offshore wind will be developed from being a marginal source of energy to be supplying about 1/3 of the European electricity demand in 2050. Norway is part of this, with a goal of 30 GW of offshore wind by 2050. It will require massive investments, for the North Sea countries about 1000 billion EUR, and for Norway, about 1/10 of that. This represents a huge opportunity for Norwegian supply industry, green jobs, and access to large amounts of renewable energy that enables cutting emissions. It also represents a significant challenge. 30 GW of offshore wind capacity means more or less a doubling of the Norwegian power system that shall be realized in about 25 years, while the existing system has been developed over more than 100 years. We must do it right so that the development provides profitability, a stable and efficient power supply, and at the same time the development must be socially and environmentally sustainable and take place in positive coexistence with all users of the sea.

The cost of offshore wind is currently higher than that of land-based, but[46,47,48,49,50,51] will be reduced through R&I and deployment, including development of efficient industrial supply chains, more efficient manufacturing, assembly and installation, and more use of remote operations, drones and IA for operation and maintenance. The wind farms may at first be connected to the mainland with radials, while an interconnected North Sea grid is expected to connect the planned large-scale developments between the North Sea countries. Some of the generation will likely be for power to x, e.g. electrolysis to produce hydrogen, possibly offshore. Power system flexibility and balancing of generation and demand will be an issue, for which new solutions will be developed. The interplay between offshore wind, hydro generation, hydrogen, both from natural gas with CCS and from electrolysis, other generation and demand flexibility, as well as the exchange of power between countries, is not trivial and calls for new methods and tools to ensure to future efficient and secure operation of the energy system. Research, innovation and education are keys to succeed. An element of success from the oil and gas development was the clear strategy to develop Norwegian expertise, realized with large private-public R&I programmes, but also requirements to share data to maximize learning across projects. This should be repeated when developing offshore wind, so that when allocating support for development, the government should set requirements for research, collection and availability of measurement data.

3.3 The role of natural gas

Currently, about 26% of the EU's natural gas is used in the power generation sector, including combined heat and power plants. Around 23% of the natural gas is utilized in industry. Most of the remaining gas is used in the residential and services sectors, primarily for heating buildings. The current demand for natural gas in the EU is approximately 350 Billion Cubic Metres (BCM) per year down from a steady gas demand of around 400 BCM per year before the Ukraine war. The share of LNG (Liquefied Natural Gas) imports increased from 20% in 2021 to 42% in 2023. Around half of that comes from the US.[52]

In 2021, Russian gas accounted for about 45% of the EU's total gas imports (pipeline and LNG). By 2023, this share had dropped to approximately 15%.[53] While LNG imports are flexible, from a price and sustainability perspective (CO_2-emissions, methane emissions), pipeline natural gas is more attractive than LNG.[54]

In 2021, 137 bcm of pipeline gas was imported to the EU from Russia, while in 2023 the volume was reduced by 82% to 25 BCM, corresponding to a 15% market share and third position in terms of pipeline imports. In 2023, Norwegian natural gas pipeline export was 109 BCM, also including exports to the UK[55]. Norwegian pipeline gas exports to EU in 2023 of 83 bcm corresponded to 49% of the pipeline total. North-Africa was the second largest source of pipeline gas to the EU, with a market share of 19%.

After 2030 and increasingly towards 2040 and 2050 the role of natural gas in the European economy depends on a few factors. First, the natural gas value chains increasingly need to become emission free as we get closer to 2040. This depends on the adaptation of CCS, technologies in industry and power generation. Second, if hydrogen markets are developed, blue hydrogen from natural gas with CCS may play a central role.

Third, if it is a target to maintain today´s levels of pipeline natural gas exports from Norway towards 2040, new field developments would be needed. Such developments should be subject to scrutiny in terms on the climate impact and target net zero in scope 1,2 and 3.

3.4 The role of hydrogen

Hydrogen is central in EU's strategy of becoming a decarbonized economy in particular since its Hydrogen strategy[56] was adopted in 2020. A strong emphasis is set on the domestic production of hydrogen from renewable resources, both from decarbonization and energy security concerns. The hydrogen will be used in hard-to-electrify applications found in the industry and transport sectors but is also seen as an opportunity for seasonal balancing in a future power system with a large share of variable wind and solar power production. Furthermore, there is a strong incentive in the EU to leverage its competitive hydrogen

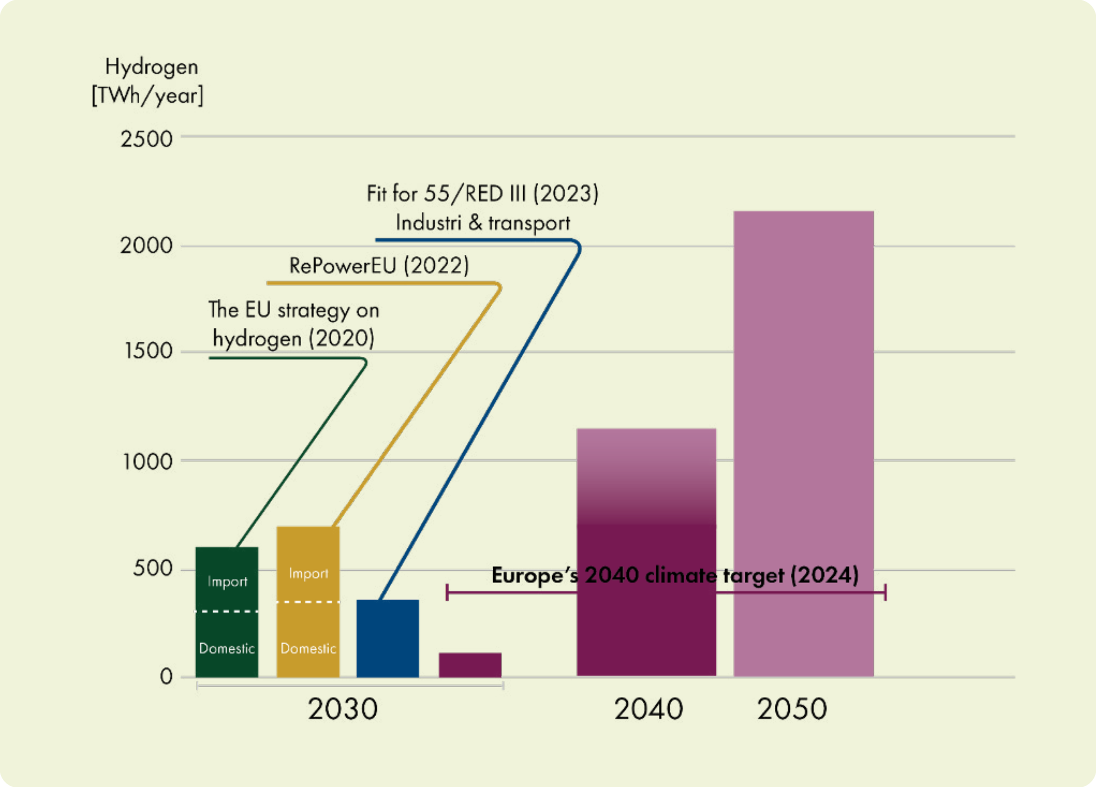

Figure 9: Overview of estimated future volumes of hydrogen consumed in EU and as set in RED III.

manufacturing industry in a potentially global developing hydrogen market.[57] The potential role of hydrogen in the EU has been developed through the later years' Fit-for-55-package, RePowerEU and the 2040 climate target assessment. Binding targets for the use of renewable fuels of non-biological origin (RFNBO, includes hydrogen produced from renewable sources) in the industry and transport sectors has been set in the updated Renewable Energy Directive (RED III)[58]. Figure 9 provides an overview of estimated future volumes of hydrogen consumed in EU and as set in RED III.

Hydrogen valleys have become a powerful tool in accelerating hydrogen deployment. These valleys also explore the opportunities in cross sector operation and cross sector coupling. For instance, by connecting production with multiple uses: from mobility, to industrial uses and as an energy system agent, storing and converting energy.

The EU targets of 10 Mton H_2 produced within the EU by 2030 and 10Mt of imports are very ambitious and is at present held up by Final Investment Decision (FID) hurdles. Less than 10% of projects end up with investment decisions. This is not exclusively an EU problem, International Energy Agency (IEA) is also reporting similar figures on a global scale. To overcome this, EU has established the Hydrogen Bank which arranges auctions to find the price of hydrogen in the market. Recently the first auction results were disclosed with seven projects on the list with strike prices about 0,45-0,5€/kg hydrogen. These are competitive prices, and all are based on electrolysis. There is a concern that imported technology at well below market prices could be involved, thus undermining the wish of growing a European vendor industry for the hydrogen economy.

Similarly, we see a growing interest in importing hydrogen as ammonia to the EU for direct use or further cracking and secondary production of hydrogen.

Transporting hydrogen is a key enabling technology. For long distances ammonia, Liquid organic hydrogen carriers (LOHC) or liquid hydrogen are competing solutions. There are significant losses involved in all these steps and such value chains should be subject to Life Cycle Assessment (LCA) to assess the sustainability.

Norway and Germany are looking into new gas pipelines for hydrogen, hydrogen produced from the onset from natural gas with Carbon capture and storage (CCS). Plans have been disclosed for export of up to 4 Mt H_2/yr, a feasibility study was concluded November 2023[59].

Low carbon hydrogen can help to accelerate the hydrogen economy whilst renewable power production is scaled up. A variety of studies have shown that the footprint of the conversion process including CCS can be made with emissions well below the EU Taxonomy threshold/renewable directive of 3.38 kg CO_2/kg hydrogen[60]. The key determining factor is the upstream emissions of methane in the production and transport of the natural gas supply. Norway has very low emission of methane in the gas value chain, estimated to below 0.03%[61]. This makes Norway a suitable supplier of low carbon hydrogen to Europe. But this demands good market interactions and predictable and stable contracts between producers, transmission operators and the consumers of hydrogen.

While hydrogen has often been seen as a tool for decarbonizing transport, we see the increased interest for using hydrogen to decarbonize important other end-use sectors like metallurgical processes, industrial heat and in combustion engines.

The North Sea provide Norway three key resources for hydrogen production for export: offshore wind power production potential, natural gas resources and vast CO_2 underground storage potential. Hence, production via electrolysis and reforming are both viable options, as well as production hydrogen for ammonia. Reforming of natural gas can be scaled up rapidly, and Norwegian hydrogen production can thus play a significant role in the first phases of the EU hydrogen market development. As larger quantities of offshore wind power become available, parts can be transformed to hydrogen and exported, using existing export infrastructure. Indeed, analyses from the CleanExport project of European energy transition shows that hydrogen export from Norway is included in the transition pathways.

In the near-future, current natural gas production rates, resource availability and competition with direct sales of natural gas to the EU are central factors that will determine the scale up of reformers in Norway. Similarly, the deployment rate of offshore wind and increasing onshore electricity demand will influence the development of electrolyser capacities. Onshore, the increasing demands are caused by the establishment of new industries (e.g. battery factories) and decarbonization of the existing industry sector as well as increasing electricity demands in the transport sector.

The pace of deployment of hydrogen is not up to the task assigned to hydrogen in the net zero society. Spearheading supply and use at larger scale whilst deploying hydrogen solutions from distributed systems will be key in making hydrogen not only the fuel of the future but the preferred solution for zero emissions where CCS and electrification are less viable solutions.

The *CleanExport* project investigated how Norway can remain an energy export nation, providing individual and collective benefits for Norway and Europe in a decarbonised European power system.

Hydrogen plays a central role in scenarios for deep decarbonisation of Europe's energy sector. Thus, it is needed in the EU and Norway. The results of the CleanExport case studies show that hydrogen is mainly produced by reforming natural gas with CCS in Norway. For larger amounts of hydrogen, electrolysis is applied in the longer term (2045 and onwards). Offshore electrolysis for hydrogen production shows promise only under a narrow range of capital costs and electricity and hydrogen market prices. However, offshore hydrogen has value in reducing curtailment in wind energy hubs.

The uncertainty in hydrogen demand leads to investment in larger production capacity and thus increased risk to investors. Policy instruments must, therefore, be in place to provide a consistent and clear pathway.

Find out more:
www.sintef.no/en/projects/2020/cleanexport

3.5 The role of CCS and the interplay between renewables, natural gas and hydrogen

CCS (Carbon dioxide Capture, transport and Storage) will play a central role in the combined efforts towards decarbonizing power generation, industry and transport, and at the same time securing the energy supply. Finally, in February 2024 the European Commission launched its first Industrial Carbon Management Strategy[62]. The European plan is to have 50 Mt CO_2/yr captured by 2030, 280 Mt CO_2/yr by 2040, and 450 Mt/yr by 2050. To be in the position to reach these targets, the policy framework, the regulations and the cost of emitting CO_2 combined with incentives need to be clear.

CCS can be used in a variety of decarbonizing strategies. CO_2 can be captured from natural gas, from the reforming process where hydrogen is produced, or from the flue gas after natural gas is used for power generation or utilized as feedstock in an industrial process. Further, industry decarbonization with CCS is an important complement to electrification, and decarbonized feedstocks as hydrogen or ammonia. The same can be said for the decarbonization of transportation where CCS can be used directly for decarbonizing maritime shipping , or indirectly as hydrogen or ammonia produced from reformed natural gas with CCS. When transforming the energy system in Europe, decarbonized natural gas will provide capacity during the transition period.

In Norway, the full-scale project Longship which is the first CCS-chain designed for open access to CO_2 transport and storage with the Joint Venture, *Northern Lights* owned by Equinor, Total and Shell, is planned to be in operation in 2025. The CO_2-capture facility at Heidelberg Materials Cement plant in Brevik is under construction. Yaras ammonia plant in Sluiskil, and the waste to energy plant at Klemetsrud have also agreements to deliver CO_2 to the Northern Lights phase one. There is also an agreement with Ørsted in Denmark to transport and store 0,43 Mt/y biogenic CO_2 emissions. The planned capacity in phase one is 1,5 Mt/yr, and a phase two with higher capacity. There are currently six CO_2-storage licenses being awarded at the Norwegian Continental Shelf. The Ministry of Energy has announced six new areas in the North Sea for applications related to CO_2-injection and -storage on the Norwegian continental shelf in 2024. For new CCS-projects in Norway to materialize, it is important that the Norwegian authorities clarify how the connection to the EUs Net Zero Industry Act will be. We need to see more CCS project in Norway making it through the investment decisions, a clear strategy for follow-up projects to Longship are missing. Norway's role as a pioneer and forerunner in the CCS area is not going to be maintained if the further development within this area is left with unclear regulations or weak support.

The Norwegian CCS Research Centre (NCCS), and the forerunner, BIGCCS have been crucial for the knowledge- and innovation capacity building within CCS. The GreenShift initiative, initiated by the Norwegian Ministries to Belgium, Germany, Denmark and the Netherlands, shows the power of bringing industry, politicians and researchers together. A set of recommendations[63] were published after the successful Düsseldorf event last year. This included advice to develop a clear policy and regulations for the business that are in the middle of, or in the planning of the decarbonization of their facilities.

In a transition perspective the natural gas end-use sectors must approach zero emissions by 2050 at the latest. That means that if natural gas is still to be used, it must be in combination with CCS or as a part of hydrogen value chains. Norwegian pipeline exports will be on a decline after 2030 unless new developments of natural gas fields take place. Considering this, it is highly important to understand the interplay between Norwegian hydropower, onshore wind, offshore wind in the North-Sea, CCS, and blue hydrogen, and how to prioritize the use of different resources.

In Duracovic et al. (2023)[64] this interplay is studied. The analyses using the EMPIRE model that features a cap on annual CO_2-emissions with a shared cap for all sectors, in line with the total targets set by the European Commission in 2018. The model results show that even with reduced natural gas availability the hydrogen market is dominated by blue hydrogen until around 2040, where green hydrogen starts making an impact. At that time the suggested volumes are around 25 million tons per year. Towards 2050 the total amounts to 30 million tons per year, with almost 2/3 coming from green hydrogen. This is matched by a massive deployment of offshore wind in the North-Sea, and with solar PV and onshore wind the most dominating technologies.

The model also suggests that the accumulated CO_2 stored in the North Sea should approach 20 GTons in 2055, with annual volumes being close to 500 MTons per year. This is close to the ambition signaled in the Net Zero Industry Act in terms of annual volumes in 2050, the latter also including use of CO_2 in CCUS while the model only considers storage, but the model suggests implementing the volumes earlier.

In a framework like this with natural gas value chains for hydrogen, ammonia, and with CCS value chains in the gigaton scale, it is likely that new Norwegian natural gas developments would have a value for Europe. The model analyses shows that better availability of pipeline gas would have an effect on the energy mix in both the power sector and the hydrogen sector. As such developments are costly, and the political risk substantial as the demand side depends on European strategies. Such new developments would need to target zero emission value chains. Long-term agreements or other risk mitigating measures would need to be in place.

4

STRATEGIC CONSIDERATIONS AND ADVICE

Strategic considerations and advice

Our main message is:

Stop reducing public investments in environmentally friendly energy research.

Investments have dropped 13% over the last 3 years, inflation corrected about 25%[65]. Norway is now only investing about 700 million NOK/yr in research for crucial solutions for the zero-emission energy system. Excellent R&I projects do not get funded in key areas such as energy efficiency, batteries, wind, solar, hydrogen and CCS. We call for an increase to 1Bn NOK per year to make an impact on our energy system and emissions by 2025 and that this amount is doubled over a 3-year period. This would be more in line with the COP28 ambitions to, among other targets, triple renewable energy capacity and double energy efficiency by 2030. The Parliament should make a new "klimaforlik" for R&I as was made in 2008. Smart financing should be employed to make sure taxpayers' money is used in an optimal way by connecting R&I actions to public investments, this applies for instance to the National Transport Plan, large scale deployment of offshore wind and public infrastructures for electricity, CO_2 and hydrogen. Research, innovation and education are key to succeed. An element of success from the oil and gas development was the clear strategy to develop Norwegian expertise, realized with large private-public R&I programmes. Another important factor was the requirement to share data to maximize learning across projects. This should be repeated when developing offshore wind, so that when allocating support for development, the government should set requirements for research, collection and availability of measurement data.

ADVICE 1: Make the grid smarter by digitalization and automation of the grid.

To enhance the existing power grids, increasing investment in research and innovation in smart and digitalized grids can boost the capacity of current grids by 20-25%, while also reducing environmental impact.

Statnett plans to invest 100-150 billion NOK in the transmission grid over the next decade[66], with additional investments of 14.5 billion NOK in regional and local grids in 2024. Norway also plans to build 30 GW of offshore wind in the North Sea, equivalent to the country's current power consumption, necessitating robust grid investments both offshore and onshore.

We also need to invest substantially in digitalization and "smartness" to increase capacity at a relatively low cost compared to investing in the physical grid. This is crucial, as implementing smart, digital solutions can yield quicker results than physical investments. To fully realize the potential of digitalization, a focus on security and risk management is essential. Norway needs a significant increase in investment in this area to ensure the grid's robustness and efficiency.

Digitalization and automation of the power grid comprise various technologies and solutions for monitoring and control of the grid, such as utilization of sensors, intelligent components, communication systems and automatic regulation systems. Extensive digitalization and automation are needed to get information about the system state enabling improved grid management and control and increasing the grid hosting capacity. One example is to utilize sensors providing dynamic capacity limits.. Some grid companies' have stated ambitions of 20-25 % increased capacity by combining such active grid measures with utilisation of flexibility.

ADVICE 2: Increase existing grid capacity by managing risk.

The current grid is built according to conservative standards, such as the "N-1 criterion," ensuring the grid can withstand the failure of one component without causing a power outage. This method focuses on the consequences but not the likelihood of events, making it inefficient and costly. The "Power grid committee" (Strømnettutvalget)[67] points out that the N-1 principle is not always economically sensible and should not be an absolute criterion for investments or connections. By moving to risk-based grid operation, it may be possible to achieve better capacity and reduced costs while ensuring a reliable and economically sensible power supply.

The available hosting grid capacity is based on technical limits to prevent voltage violations, disturbances, and supply interruptions. These limits are currently conservative and static due to limited information on the system's operating state. Research and pilot projects in CINELDI have shown that grid monitoring and decision support can enable dynamic limits.

The NOU report "More of Everything – Faster"[68] discussed the possibility of grid companies taking higher risks and increasing hosting capacity by deviating from the N-1 criterion. The European research project GARPUR[69] developed probabilistic reliability criteria, demonstrating a better balance between supply reliability and socio-economic costs. Using these criteria allows for risk-based planning and operation, enabling power grids to operate closer to their limits. However, it needs to be further investigated if we would be willing to increase the hosting capacity by taking a higher risk. This is an area of research in the upcoming FME SecurEL research centre starting in 2025.

ADVICE 3: Promote local solutions, remove bottlenecks, and utilize flexibility resources.

Better local coordination of demand and supply will allow better grid utilization, save investments, increase resilience and allow new connections of end-users where the grid would otherwise be constrained.

Bottlenecks in the power grid create price differences between areas, limit new connections, and can delay the electrification of sectors such as process industries and transport. Renewable energy sources like wind and solar make power supply more unpredictable, but a smart grid helps manage variations and balance energy. End-user flexibility, such as adjusting industrial consumption, heating and electric vehicle charging, can follow renewable energy production and better utilize grid capacity.

Energy use in buildings, can be time-flexible without compromising user comfort, aligning consumption more closely with renewable energy production. Energy societies can coordinate local energy consumption with local generation to reduce grid bottlenecks and improve grid utilization. Conditional connections could allow more flexible consumers into the grids by offering non-firm capacity during grid congestion. Local flexibility markets could further enhance resource utilization by allowing end-users and energy generators to sell flexibility, improving local energy balance. Future energy systems need a better understanding of flexibility service demand, more coordination to avoid new problems, and opportunities for end-users to offer flexibility services without disadvantaging vulnerable users.

Effective coordination requires new regulations, tariff schemes, and incentives for local investments. Both flexibility markets and regulation that allow internal trading and coordination in energy societies are needed. At the same time, these new schemes must respect the need to recover grid costs and distribute these fairly.

ADVICE 4: Increase renewable energy production, together with efforts for energy efficiency and infrastructure development.

With our current industrial structure, energy policies, and industrial policies, the demand for more clean energy is increasing. Our economic models show that the main barrier that may prevent us from maintaining economic growth and welfare is shortage of clean electricity. Sufficient availability of energy is also key to future security of supply.

We should save as much energy as possible and ensure efficient use of the energy we must consume. The energy efficiency potential in houses and industry has been assessed to be about 30 TWh, i.e. about 20% of the current demand for electricity. The government should demand efficient use of energy, also from tapping from our natural resources and make sure we have high standards and support mechanisms to encourage this. It is surprising to see how little support there is for R&I in these areas in Norway, efficiency pays off and should be supported at a healthy level.

Before 2030 the new energy and peak load needs must be covered by onshore wind and increased hydropower capacity expansions in production and pumping.

The realisation of 30 GW of offshore wind in 2040 means almost doubling the Norwegian power system with access to large amounts of renewable energy that enable new green industry and cutting emissions through electrification. This represents both great opportunities and challenges. The land-based power system has been built up over the course of more than 100 years. The new power system that will be built offshore will be completed in less than 15 years. The development of the power system in the North Sea must ensure profitability, and a secure and efficient power supply, at the same time the development must be socially and environmentally sustainable and take place in positive coexistence with all users of the sea. Our analyses shows that this is best secured in cooperation with other European countries as the total offshore wind volumes in the area will be between 180-300 GW installed capacity. The ocean areas in the North-Sea and further north may be the European areas with the highest energy surplus. Much of its value lies in being well connected to large parts of Europe.

ADVICE 5: Achieve zero emissions in natural gas value chains by 2050 and in new field developments by 2040. These value chains are crucial for European security of supply and for meeting European climate goals.

Our analyses show that natural gas value chains and hydrogen value chains with CCS will play a key role in decarbonizing European industry. Natural gas with CCS and clean hydrogen may at the same time play a central role for European energy security.

The European power sector needs to go zero emission sometime between 2040 and 2050. In 2040 the European industrial sectors need to be far on its way to decarbonization and in 2050 close to zero emission. The demand for CCS and for hydrogen strongly depends on industrial decarbonization in Europe. Unless industrial decarbonization happens, Europe will not meet its climate goals. Planned Norwegian natural gas export in current fields will decline between 2030 and 2040. Based on the above, new natural gas field developments must be part of zero emission value chains with CCS, including blue hydrogen value chains.

ADVICE 6: Strengthen European cooperation on large-scale infrastructures for CCS, hydrogen, and the offshore grid.

The interplay between natural gas, CCS, hydrogen and renewables is critical for Europe´s capabilities to decarbonize and for European energy security. At the same these technologies may be a source for Norwegian value creation. The combination of the high volumes required and the pace at which the need to be implemented require considerations of how to succeed. There is a need for long-term agreements between the supply side and demand side (for hydrogen, for CO_2, for natural gas) to reduce volume risk, price risk and political risk for commercial actors that will use and operate these infrastructures. There is a need for learning across project and research on how to accelerate infrastructure problems and there is a need for more research on biodiversity, land use and sustainable scaling of such infrastructures. We need to understand what role both the government and industry in Norway will play or seek to play in "de-risking" value chains related to energy transitions in Norway and Europe. Without deliberation and local participation, these projects may affect communities in adverse ways and/or might meet resistance from local communities.

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