NTNU
Norwegian University of
Science and Technology

Preparing a future EU strategy on energy sector integration

Introduction and Executive summary

Norway´s strategy is structured around five closely interrelated themes addressing: (i) energy security of supply security, (ii) a fully integrated energy market, (iii) energy efficiency, (iv) decarbonising the economy and (v) research, innovation and competitiveness. Norway supplies between 20% and 25% of the EU gas demand by pipelines to Germany, Belgium, UK and France. The country is also a **large producer of renewable electricity** (98%), with hydropower being the source of most of the generation followed by wind and thermal power. As the industry and market currently indicate, Norway is very well placed to be one of the major world exporters of hydrogen and in particular of blue hydrogen produced from natural gas (SMR – steam methane reforming process with CCS - Carbon Capture and Storage) and green hydrogen produced from water electrolysers powered by renewable energy systems (RES). Moreover, Norway is home of the largest manufacturer of low temperature water electrolysers with systems deployed worldwide.

Norway is part of a joint Nordic power market with Sweden, Denmark and Finland, and this is in turn integrated into the wider European power market through interconnectors to the Netherlands, Germany, the Baltic states, Poland and Russia. Two new interconnectors with Germany and the UK are scheduled for completion in the course of 2020 and 2021.

In the overall Norwegian Energy landscape, the Norwegian University of Science and Technology (NTNU), the largest public research university in Norway with campuses in Trondheim, Gjøvik and Ålesund with over 8,000 employees and over 40,000 students, plays an important role and has the main national responsibility for education and research in engineering, science and technology.

From NTNU’s viewpoint, our focus is on hydrogen, offshore wind technologies and the maritime sector as the three main priority areas for energy sector integration. Very recently, the Mongstad[1] site (one of the country's largest industrial areas) has been chosen as the preferred location for what may be **Norway's first liquid hydrogen production plant** for the maritime industry.

List out challenges and suggested advices

The Nordic power exchange, Nord Pool, was established at an early stage where considerable experiences have been achieved concerning the electricity market. Combining the large storage capacity of the Norwegian hydropower with variable renewable energy, like wind and solar, can provide an improved **flexibility in the electricity market**. Natural gas pipelines and storage as electricity interconnections can play a flexibility role in the energy sector in Europe. Hydrogen as an energy carrier has a great opportunity as flexibility provider. The EU vision for 2030 is to have circa 40GW of water electrolysers installed, capable of producing zero emission hydrogen at a price lower than €3/kg. However, the energy transition in the EU will require significant amount of hydrogen at large scale until the power sector is fully decarbonised.

The development of long-term energy strategy is a key for creating conditions and perspectives enabling significant **integration of RES** into the power system.

- **Integration across institutions.** Large scale RES installations are often located in remote areas, calling for needs to strengthen the transmission grids for transferring

[1] https://tcmda.com/

the energy to the demand regions. Huge investments are undertaken to build long distance HVAC and HVDC interconnections. Transmission System Operator (**TSO**) and Distribution System Operator (**DSO**) must thus play an important role. Significant efforts and investments to develop different types of microgrids, local energy communities, integrating distributed generation, local energy storage (batteries) and demand side management are needed. To obtain a flexible and well-functioning integrated energy market, obstacles in the system must be removed through improved regulations and harmonisation at EU level.

- **Electricity system requirements**. A successful introduction of new elements/players and developments to the system has to consider the challenges in the physical requirements of the grid such as **transfer capacity**, **equilibrium** and **variability**, with respect to degrees of uncertainty, in generation and demand. Voltage supporting possibilities are key for **maintaining voltage levels** in the grid, while accurate **quantification of local resources** can be utilised for balancing services, including flexible demand.

- **Policy**, **legislation** and **market design** are required in order to address a number of challenges:
    - Regulation and market design that supports coordinated **short-term resource allocation** in heat, natural gas and electricity markets
    - Regulation that incentivises **cross border cooperation** on CCS infrastructure for transport and the connected storages
    - Technology neutral regulation and incentives for **emission free** hydrogen and ammonia production
    - Create incentives for cross-border cooperation and market design for **transmission** and **joint developments** like large scale floating offshore wind farms
    - Regulation and market design that incentivise, the interaction with **zero emission transport vehicles** and the energy system, through hydrogen, as both as fuel and a storage option, and battery electric operation and storage

For **hydrogen technology deployment and implementation**:

- At EU levels, regulatory gaps exist due to the absence of regulatory harmonisation, as some European regions have their own legal frameworks to support (or not) Power-to-Gas (P2G) operations and assess the hydrogen quality before its use in distribution gas networks and systems. At present, there is no European coordinated approach and joint efforts related to health & safety and technical integrity for hydrogen injection into the natural gas grid networks[2]. One of the suggested advices to overcome this is to impose **uniform regulatory legislations** across Europe.
- The current cost of water electrolyser systems is high due to components, systems and manufacturing cost.
- A **complete hydrogen economy** and supply chain must be developed through renewable hydrogen production, hydrogen fuel cell systems for use in domestic and industrial applications.

[2] Gunhild Allard Reigstad et al., Hydrogen for Europe - Final report of the pre-study, SINTEF Energy Research, 22.08.2019

1. What would be the main features of a truly integrated energy system to enable a climate neutral future?

In the last decade, variable renewable energy has entered a path of sustained growth. The key energy transition challenges thus shift towards integrating large shares of renewables through additional flexibility. The energy system develops to become more decentralised, decarbonised and digitalised and electricity has increased importance as an energy carrier. To achieve a climate neutral future, electricity generation as well as the gases utilised needs to be decarbonised. **Flexibility and market design** are the most fundamental characteristics of future European energy systems. Energy storage systems such as hydropower, batteries and hydrogen both for longer terms and short-term operations will be needed to achieve flexibility. The energy sector is crucial for transitions to low-carbon societies by decarbonizing other key emitting sectors, such as transport and industry. A decentralised system will foster more decisions to be taken by consumers and end-users as choices will be available both for use of electricity and heat in the stationary energy systems as well as energy carriers in the transport system. Decarbonisation and decentralization in the energy sector lead to the need for improved digitalisation. An integrated energy system of smart devices from various stakeholders must interact seamlessly and reliable with each other in order to provide a stable power supply. The system operators (Transmission System Operator (TSO) and Distribution System Operator (DSO)) must therefore play an important role. To obtain a flexible and well-functioning integrated energy marked, obstacles in the system must be removed through improved regulations and harmonisation at EU level.

2. Where do you see benefits or synergies?

Synergies in the electricity system operation

Fully decarbonised and sustainable electricity system challenging also TSOs to create, develop and implement various solutions to adapt and extend the existing system. Numerous challenges (need for **technology**, **implementation** and **financing**) shall solve grid capacity scarcity problem, which not only severely hinders the further RES integration but also leading to the grid congestions, which in return should be mainly resolved via expensive and CO_2 intensive re-dispatch measures. Other means of strengthening the bulk power system includes utility scale generation enabling closer integration of electricity markets on the global scale[3].

As well as, it is important to establish smart and secure **collaboration schemes between TSO, DSO and consumers** in order to increase the energy system resiliency. TSO and DSOs are responsible for safe and reliable grid operation and they both have a specific need for flexibility. The DSO's roles would shift towards an active system operator. To facilitate the transition to new roles, it is also important to **encourage the transition process from DNO to DSO** (Distribution Network Operator to Distribution System Operator), to emphasize the value and importance of DNO managing their network more flexible for a cost-effective low carbon transition.

Thus, new tasks might be the procurement and activation of **flexibility in order to avoid congestions or voltage problems**. Where the DSO products would be applicable for congestion and voltage management purposes and would consist of active and reactive power

[3] It is noted that the ongoing projects NordLink and NorthSeaLink (NSL) contributes with 1,400MW to Germany and Great Britain and will operate from 2021. In addition, Viking Link, Kriegers Flak, Hansa PowerBridge and Sydvästlänken are expected in 2025, while a new cable between Norway and Great Britain is under consideration.

flexibility. For such type **DSO's products**, the geographical aspect is particularly important. Therefore, the products must be tagged e.g. with the metering point reference number allocating them to the respective network node.

Synergies between sectors and systems

The different sectors, their policies (climate, industrial, and energy), technologies, and actor constellations (citizens, companies, and policymakers) are all linked by the energy system. As variable renewable energy enters a path of sustained growth, key energy transition challenges shift towards integrating large shares of renewables through additional flexibility. In this lies also the main benefits of sector integration. On one hand, clean electricity and heat generation enables substitution of CO_2 emitting fuels, feed stock and energy carriers in these sectors but at the cost of increased intermittency and variation at the supply side. Then the flexibility provided at the demand side in these sectors through integration measure like the following is critical:

- Flexible short-term substitution between thermal heat systems and electricity in energy systems my play a central role in resolving short-term imbalances.
- Flexible demand side management through demand response for consumers and industry
- Storage of energy in hydrogen and batteries in the transport sector for balancing of sully and demand
- Cross border initiatives for large scale transmission utilizing the flexibility in large scale hydropower with reservoirs and the often attractively uncorrelated wind generation in different geographical locations.

3. Where do you see the biggest energy efficiency and cost-efficiency potential through system integration?

While energy efficiency by new technology development in the supply, transport and storage as well as in the end-use systems is important in system integration, for example in using heat from industry, CHP plants, heat pumps and similar, the main benefits comes for the ability to reduce or remove the effects from temporal and geographical imbalances in demand and supply. System integration including a) short-term substitution between heat and electricity b) involvement of active consumers locally and c) cross border coordination and transmission between countries may provide the cost-efficient way of balancing supply and demand on horizons ranging from minutes to a few weeks. So, when considering design elements of an integrated energy system the focus should be equal on cost efficiency in flexibility provision and energy efficiency measures, serving two different purposes.

4. What are the main barriers to energy system integration that would require to be addressed in your view?

Infrastructure needs: Integration of heat systems based on renewable gases or hydrogen from natural gas including CCS with the electricity systems may lead to major benefits from both the flexibility perspective and from reducing needs to build new electricity distribution grids. On the other hand, developing the infrastructure and value chains needed for example for hydrogen or modifying existing ones like the natural gas pipelines is still a major barrier.

Inclusion of the citizens: One major question is how the scope of the transition and system integration can be *widened* to include citizens and their interaction with technologies and systems? *More insights into how to create inclusive engagement in energy transitions and sustainable practices is required.* New practices, increased citizen engagement, and changes in behaviour and culture are key to stimulate demand for low-carbon solutions, to create political legitimacy, and to mobilize the resources needed for the transition and system integration. Changes are constrained by path dependencies resulting from design, technological, investment, planning, and construction decisions, as well as from social inertia generated by culture, norms, customs, and routines.

A major question is how we can accelerate the transition to low-carbon societies?
This calls for radical innovations, but also massive deployment of existing technologies, such as hydrogen, biofuels, offshore wind, and CCS. Enabling technologies like digitalisation may play a major role in these innovations. However, transforming towards deep decarbonisation requires looking beyond single technologies and sectors to understand how the energy transition can be accelerated. Whereas earlier transitions were driven by new technologies/resource discoveries, the current energy transition is purposive, in which policy has a key role. A key aspect is aligning transition and industrial goals to mobilise businesses and legitimize transition policies, and to delegitimize unsustainable practices by mobilizing citizens. The knowledge needs are:

- To understand which actors, drive the acceleration of the transition and who hampers the process, as well as how cooperation between public and private actors may affect the acceleration
- How policy can impact both the rate and direction of innovation across sectors in the acceleration of the energy transition
- More knowledge about whether and how system technologies such as storage, digitalization and other enabling technologies can impact the pace of the energy transition.

5. More specifically:

a. How could electricity drive increased decarbonisation in other sectors? In which other sectors do you see a key role for electricity use?

There are many possibilities both in the buildings, transport, industry sectors. In the domestic heating (through heat pumps and renewable hydrogen in fuel cell for combined heat and power - CHP). In the land-based transport sector cars, vans, buses, short distance trucks and motorcycles as well as rail transport. As an example, the development in the use of electric cars has been rapid with 270,000 BEV (Battery Electric Vehicle) and 115,000 PHEV (Plug-in Hybrid Electric Vehicle) sold in Norway at the end of 2019. The Norwegian Parliament has suggested a ban on new sales of fossil fuelled cars from 2025.

The building and construction sectors currently use many machines that run on diesel. Battery-electric excavators, wheeled loaders, dumpers and concrete vehicles, for example, have already been developed. In addition to greenhouse gas emissions, electrification will make it possible to reduce noise and various types of pollution (e.g. PM_{10} particulates).

In addition, electrification in the maritime transport like ferries and short distance ship transport as well as solutions with hydrogen, battery-electric, hybrids or contact lines may be possible. Power supply from shore means connecting to the grid when maritime vessels are docked at the quayside. Most of this consumption comes from offshore supply ships, passenger ships and cargo ships. Short distance aircraft transport has also been demonstrated.

In the industry sector, one example is the use of high temperature heat pumps in industrial applications replacing fossil fuels. Heat pump solutions have mostly been limited to temperatures up to 80°C, research activities of High Temperature Heat Pumps (HTHPs) with heat sink temperatures in the range of 90 to 160°C are currently being performed. The focus is on heat pump cycles and the suitable refrigerants. Several manufacturers have now developed the first solutions to provide heat sink temperatures of at least 90°C. There is a large application potential particularly in the food, paper, metal and chemical industries at heating capacities ranging from about 20kW to 20MW.

b. What role should electrification play in the integrated energy system?

Renewable power is outcompeting all other sources of electricity when new capacity is needed. Renewable electricity does not face cost driving factors as non-renewable sources. Utilising renewable power, successful economic development makes further economic development easier, as costs of electricity decrease. This has been experienced in the supply side, now is the time to develop technology and solutions further in the end-use side.

c. What role should renewable gases play in the integrated energy system?

Renewable gases have traditionally been used in the local environment for electricity and heat in farms and local communities. New processes and technologies have made liquid biogas (BGL) competitive also in the transport sector for trucks, buses as well as the maritime transport. One Norwegian example is Biokraft, the world largest BGL-plant[4].

d. What measures should be taken to promote decarbonised gases?

Carbon Dioxide Capture, Transport and Storage (CCS) is one of the main objectives of the European energy policy, the low carbon policy. Most of the European countries are focusing on decarbonizing the power sector and energy intensive industry and thus reducing anthropogenic CO_2 emissions. Costs and storage issues have greatly impacted on the use of hydrogen as a fuel. The hydrogen retail price in Europe is ca. €10/kg. Hydrogen production costs depend upon the process, feedstock and production capacity and capability. In general, production from fossil fuels offers competitive prices and large-scale potential but cannot be considered a viable option for large scale production in the absence of effective CCS.

The Global CCS Institute[5] give information, a database of facilities worldwide ranging from large scale, pilot and demonstration to test centres. European activities towards CCS are served by two entities: The Zero Emission Platform (ZEP) and the European Energy Research Alliance Joint Programme on CCS (EERA JP-CCS). ZEP is a unique coalition of stakeholders and acts as advisor to the European Commission on the research, demonstration and deployment of CCS for combating climate change. 19 different countries contribute actively to ZEP's activities, while 40 different companies and organisations comprise the Advisory Council. The EERA Joint Programme on CCS (EERA JP-CCS) has a strong R&D focus and encompasses 40 public European research centres and universities working on a common programme. The EERA JP-CCS including a new CO_2 transport sub programme and has contributed to the SET Plan Integrated Roadmap. Technology Centre Mongstad (TCM) is the world’s largest facility for testing and improving CO_2 capture able to capture 100,000tonnes CO_2/year. A new legal operation agreement for TCM was established through early 2020. The major open access RI on the ESFRI roadmap is ECCSEL-ERIC (European Research Infrastructure Consortium) for researchers to a top-quality European research infrastructure devoted to second and third generation CCS technologies.

---

[4] https://bioenergyinternational.com/biogas/biokraft-inaugurate-worlds-largest-liquefied-biomethane-plant

[5] https://www.globalccsinstitute.com/

Long-term monitoring and documentation of stored CO_2 in geological reservoirs have been achieved. The Sleipner CO_2 Storage facility was the first in the world to inject CO_2 into a dedicated offshore geological sandstone reservoir since 1996 and over 16.5million tonnes has been injected at the end of 2016. The Snøhvit CO_2 Storage facilities has captured more than 4million tonnes of CO_2 at an LNG facility in northern Norway and transported in a pipeline back to the Snøhvit field offshore and injected into a storage reservoir.

To capture CO_2 from industrial processes has some advantages like lower capture cost, excess energy that can be used for CO_2 capture and stable CO_2 source. Industrial cement plants are often located in industrial clusters/coastal locations which can possibly lower transport cost. There are two pilot plants for capturing carbon in Norway; Norcem AS (cement plant) and Klemetsrudanlegget AS (waste-to-energy-recovery plant) selected for detailed studies of full-scale carbon capture at their respective plants. The total CO_2 injection capacity for all three plants in full scale operation is approximately 1.3Mtpa. A combined pipeline and shipping system are being examined for CO_2 storage in the **Northern Lights**[6] full scale project in Norway, which is located offshore. A final investment decision is targeted for 2021 with the ambition to begin operation in 2024. Developing a safe storage solution for CO_2 will thus give an infrastructure for decarbonising large industries as well as production of large-scale hydrogen from natural gas.

In contrast, electrolysis is costly, but involves no or even negligible emissions (apart from those from electricity generation) and produces high-purity hydrogen (99.999%). For hydrogen storage, compression energy amounts to 10-15% of the hydrogen energy content (up to 30% for very high pressure). Renewable hydrogen at the "pump" could reach €5/kg depending on the electricity costs. Thus, the electricity prices are vital for the price development of hydrogen. By 2030, the hydrogen cost could reach <€3/kg (based on €500/kW Capex, 50kWh/kg efficiency, €50/MWh electricity).

e. What role should hydrogen play and how its development and deployment could be supported by the EU?

The annual average wind electricity production in Norway is ca. 5.5TWh with a theoretical onshore and offshore wind potentials estimated at ca. 1,000TWh/yr and 14,000TWh/yr respectively. In that context, Norway has taken a leading role in rolling out hydrogen technologies and systems. For example, the Norwegian industry and research organisations are in project collaborations with Asko (Norway's largest grocery wholesaler), Yara (Norway, ammonia producer), Hybrit Development AB (Sweden, steel manufacturer), Shell (US & Denmark), Nikola (US, truck manufacturer), to name but a few. In the €5m FCH-JU funded project – Haeolus, a 2MW electrolyser was installed and connected to the Raggovida wind park (45MW) to produce 1tonne of hydrogen per year to be shipped out as liquified hydrogen.

The large deployment of RES has completely changed the power generation sector, leading to energy markets dominated by high intermittency of renewable power generation systems. As an example, offshore wind energy, which has an installed capacity potential of up to 1,000GW, is an important pillar of the European energy transition. The EU's energy transition therefore requires a complete decarbonised power generation sector, suggesting the requirement to

[6] https://northernlightsccs.com/en/about

integrate RES into the grid. Blue hydrogen should be regarded as a short-term solution to allow a swift hydrogen economy transition, with green hydrogen offering better outlooks for a European sustainable economy[7]. Hydrogen is to play a paramount role in decarbonising sectors in Europe which have not been straight-forward to electrify such as the transport, energy-intensive and heavy industries and power generation sectors. Hydrogen is the only at-scale technology available for long-term energy storage as it can be stored (and transported) in existing gas grids and salt caverns for long periods of time at relatively low cost. It also provides a link between European areas with low-cost and highly available renewable energy i.e. connecting European regions with abundant renewable energy with others which have less and even none. Hydrogen allows long-distance transportation of energy in pipelines, ships and trucks, either gaseous, liquified, or stored in other forms (e.g. metal hydride, ammonia, methanol etc), which costs much less than electrical power transmission lines. Hydrogen should be regarded as a strong decarbonisation and an essential lever among a portfolio of other technologies as it enables large-scale RES possible as hydrogen can be produced and stored. In the case of electrolytic hydrogen, European manufacturers are well placed to keep Europe as the global leader on water electrolyser technology, securing high value manufacturing jobs (most of the global electrolyser manufacturers are based in Europe). Although there is still considerable room for innovation to improve materials and systems costs and an important role for large scale systems with economies of scale. The EU vision for 2030 is to have ca. 40GW of water electrolysers installed in Europe, capable of producing zero emission hydrogen at <€3/kg. Depending upon the hydrogen market size and the role of electrification both may be required also in the long run.

g. How can energy markets contribute to a more integrated energy system?

Market design: Energy transitions should be anchored in a well-functioning energy market, allocating energy system resources optimally in the short term, while providing investment incentives for optimal resource allocation in the long term. The long-term goals include welfare, fairness, sustainability, and security of supply. One challenge in designing markets is to meet these goals and understand the interplay between short-term system operation, market functions, and integration with transport, building, and industry sectors. Currently, low-carbon generation integration is supported by different mechanisms (e.g. FiT, certificates, and tariff designs). However, new market designs are needed to enable the integration of renewables and investments in system services, such as storage and smart grids. Additionally, active consumer market participation and prospects provided by digitalization and distributed ledger technologies are key[8].

The knowledge needs are as follows:

- To understand the future interrelated marketplaces for energy, flexibility and services, the products traded in them, and the emergence of new types of actors related to sector integration)
- To understand digitalisation opportunities for efficient allocation of resources based on products, contracts, and services, focusing on the qualities of the energy and active consumer participation

[7] Claudia Siew Wan Cheng, The prospects of blue and green hydrogen in Norway for energy export, Master Thesis, University of Stavanger (UiS), Norway, January 2020.

[8] https://cityxchange.eu/about-cityxchange/

- To increase the knowledge about how regulations and policies at EU level affect Norwegian energy market design and the exploitation and value of Norwegian resources in the energy transition
- In a context of Energy and Climate Policy integration and high penetration of intermitted renewables and distributed energy resources, the smartening and digitalization of distribution grids enables unlocking the potential of distributed flexibilities and **new business models with a focus on DSOs, aggregators, end-users, and data service providers**.

The challenges and opportunities for these stakeholders could lead to the changes in the power system, with an emphasis on perspective of the **new role of the active DSO as market facilitator and distribution system optimizer.**

h. How can cost-efficient use and development of energy infrastructure and digitalisation enable an integration of the energy system?

Digital (ICT) systems and Smart Grids interoperability

Decarbonisation and decentralisation in the energy sector lead to the need for energy digitalisation. Where an integrated system of systems with ICT-systems and smart devices from various stakeholders have to interact seamlessly and reliable with each other in order to provide a stable power supply. Consequentially, one of the main challenges is to enable and to secure **long-term interoperability between the digital systems** in Smart Grids.

Smart, energy-saving network connectivity on the end-user level requires big data and powerful data processing in the smart grid infrastructure. They can manage and automate services such as lighting, heating/cooling and washing in order to reduce energy consumption and provide load flexibility to the grid. Despite recent gains in building envelope and appliance efficiency, further opportunities remain to improve whole-building system efficiency through smart homes. However, there are significant barriers:

- High costs and unclear benefits: smart devices cost more and suffer from a lack of consumer confidence about their benefits.
- Privacy, trust and security: consumers are concerned about misuse of data in the cloud and hacking of data and devices.
- Complexity and technology risk: smart homes involve new and complex technologies which many consumers fear may not work as intended and are difficult to operate. Problems of interoperability between new and legacy devices are common and this tends to increase consumer concerns.

Key challenge here is continued with a definition and characterisation of the various types of the required interoperability and its taxonomies in reference to the **dimensions of interoperability (operational technologies, information technology and cyber security)** and its quality. Block chain and machine learning certainly can help towards integration. Block chain in the energy segment is however highly dependent on credibility that political regulations can ensure, so that energy sold or integrated is actually physically sensible.

1. Are there any best practices or concrete projects for an integrated energy system you would like to highlight?

Several regional demonstration sites exist using different renewable energy sources including electricity production, transport, storage and end-use. One example is the HyDeploy project [9].

The Mongstad[10] site (one of the country's largest industrial areas) has been chosen as the preferred location for what may be Norway's first liquid hydrogen production plant for the maritime industry.

+CityxChange (Positive City ExChange) is a smart city project, that has been granted funding from the European Union's Horizon 2020 research and innovation programme in the call for 'Smart cities and communities.' The Norwegian University of Science and Technology (NTNU) is the host and leads the +CityxChange consortium together with the Lighthouse Cities, Trondheim Kommune and Limerick City County Council[11].

2. What policy actions and legislative measures could the Commission take to foster an integration of the energy system

Policy – In practice political decision support has to deal with the full complexity of the problem, which arises mainly from the requirement. Some of the measures needed are:

- Regulation and market design that supports coordinated short-term resource allocation in heat, natural gas and electricity markets
- Regulation that incentivises cross border cooperation on CCS infrastructure for transport and the connected storages
- Technology neutral regulation and incentives for emission free hydrogen and ammonia production
- Increased incentives and market design promoting cross-border cooperation for transmission and joint developments like large scale floating offshore wind.
- Regulation and market design that incentivise, the interaction with zero emission transport vehicles and the energy system, through hydrogen as both a fuel and a storage option and battery electric operation and storage.

Challenges – *Legislations*: EU legislation has a major impact on the use of hydrogen as a fuel. Relatively high economic challenges exist for stationary power in residential and commercial buildings due to the absence of financial incentives. A better understanding on the feasibility of hydrogen systems and technologies deployment rates related to hydrogen production and energy storage e.g. large-scale hydrogen storage is required[12]. *Technology*: The technology is key to enabling a decarbonised energy system, enabling increasing proportions of intermittent renewable generation, and acting as an energy vector. There are still considerable potentials for innovation to improve component and system efficiency, performance and durability. *Cost*: Currently water electrolysers are expensive. There is an important role for large scale systems with economies of scale, and hydrogen distribution to end uses in the electricity distribution networks.

[9] https://hydeploy.co.uk/

[10] https://tcmda.com/

[11] https://cityxchange.eu/about-cityxchange/

[12] Gunhild Allard Reigstad *et al*., Hydrogen for Europe - Final report of the pre-study, SINTEF Energy Research, 22.08.2019.

Technologies dissemination	Energy System Management	Risks assessment
New power consuming technologies with different energy efficiency and flexibility types	Demand Response: Demand-side Management	Climate change impact consumption and the energy system
Smart Homes, smart equipment, smart grids, smart integrated systems	Interrelations between Consumer Groups (CGs) and Energy Management System or Energy Service providers on distribution level. Large scale utilisation of demand side flexibilities, generation and storage requires good coordination between TSO, DSO and CGs	Cyber-attacks on a decentralized and digitalized energy system, Development of grid tariffs and regulation may either enable of block participation of distributed flexibilities
Power generation: central, decentral – renewables and fossils – different flexibilities and inertia	New electricity market models needed to enable distribution of resources. Markets and grid management increasingly interconnected.	Volatility of RES. Lack of inertia. High balancing costs with centralised resources. Distributed flexibilities are behind distribution grid constraints managed with more or less vulnerable coordination
Storages: central, decentral – private, district, fixed - moving	Using distributed storages for system flexibility through the distribution grids requires complex coordination. Distributed storage improves the reliability of power supply for the CGs.	Centralising storages increases vulnerability of the CGs
Markets for electricity and its ancillary services	New possibly complex market architectures	Market failures

Author names:

Prof. Asgeir Tomasgard: Director of FME NTRANS and Director of NTNU Energy Transition Initiative

Prof. Bruno G. Pollet: Leader of NTNU Hydrogen team

Dr. Eleni Patanou: Coordinator of NTNU Energy

Prof. Irina Oleinikova: Leader of NTNU Smart Grid team

Prof. Johan E. Hustad: Director of NTNU Energy

Massimo Busuoli: Director of NTNU Brussels office

Prof. Odne S. Burheim: Leader of ENERSENSE