

Incentives and barriers to flexible operations of industrial processes and district heating production to increase intermittent renewable electricity production — an interview study with involved actors

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Abstract

The Paris Agreement sets a framework to reach a goal of limiting the increase in global average temperature to well below 2 °C above pre-industrial levels. Actions to reduce greenhouse emissions include increasing the share of renewable electricity production and improving energy efficiency.

However, this implies challenges related to the intermittent nature of wind and solar power. One way to enable an increased share of intermittent electricity production is to increase flexibility on the demand side. A district heating system that includes centrally controlled heat pumps and combined heat and power plants, together with load management of industrial processes, can provide a platform for an increased share of intermittent renewable power generation.

Previous studies have analysed technical potentials for flexible operations that can increase the share of intermittent renewable electricity production. However, the view of the actors involved has not been analysed. Therefore, the aim of the present study is to analyse the industry's and the energy sector's perceptions of the potentials and challenges related to flexible operations.

Actors from industry and energy companies in Sweden were interviewed to appraise and evaluate how they perceive the potentials and challenges regarding sector coupling and flexible operations. Challenges identified are trade-offs between balancing the electricity grid and cost-optimisation at company

level, and that the strategy requires a smart control system and targeting regulations.

The results from the study can guide policymakers when formulating policies that can stimulate marketplaces for flexible operation that will enable an increased share of intermittent renewable electricity production and reduce the risk of power capacity shortages.

Introduction

The Intergovernmental Panel on Climate Change Actions (IPCC) released its sixth assessment report on 9 August 2021, stating that there is an unequivocal connection between human emissions of greenhouse gases and the increase in the global average temperature (IPCC, 2021). The Paris Agreement sets a framework to reach a goal of limiting the increase in global average temperature to well below 2 °C above pre-industrial levels. Moreover, the Swedish environmental goal is to achieve net-zero greenhouse gas emissions by 2045 (Sveriges regering, 2017).

According to the energy agreement from 2016 (Sveriges regering, 2016), the goal for Swedish electricity production is that it should be 100 % renewable by 2040. Furthermore, the goal of reaching net-zero greenhouse gas emissions has incentivised the electrification of transport and industry (Son et al., 2022), which will increase the need for renewable electricity (e.g. solar and wind power) in the system. However, solar and wind are intermittent energy sources, which entails a challenge when increasing their share in the electricity system. Traditionally, the energy system has been balanced on

the supply side by regulating production, but the increased share of intermittent electricity means that demand-side flexibility must also be included (Connolly and Mathiesen, 2014; Mathiesen et al., 2015). This is often referred to as demand-response, and actions include load management at company level and aggregation of power demand, where large groups of electrical loads can be controlled as a single entity to reduce their aggregate power demand in the electricity network. In this paper, flexibility is defined as the ability to change the production or use of electricity compared to the planned or expected condition.

Historically, there has been a focus on energy security (Martchamadol and Kumar, 2013). However, the current and future situations also highlight the need for power security (Gouveia et al., 2014). Several previous researchers have highlighted integrated energy systems and sector coupling (so-called smart energy systems) as part of the solution to enhance grid stability and flexibility (Berjawi et al., 2021; Connolly and Mathiesen, 2014; Lund et al., 2016a; Mathiesen et al., 2015; Ramsebner et al., 2021). Examples of sector coupling that aims to enable an increased share of intermittent electricity production include: (1) the introduction of hydrogen solutions (production of hydrogen by electrolysis and electricity production from hydrogen during the periods of high and low intermittent electricity production, respectively) (Connolly and Mathiesen, 2014; Lund et al., 2016a; Mathiesen and Lund, 2009; Mathiesen et al., 2015), (2) the use of electric vehicles as flexible demand (Connolly and Mathiesen, 2014; Doumen and Paterakis, 2019; Lund et al., 2016a; Sadeghianpourhamami et al., 2018); and (3) collaboration between the electricity and district heating (DH) sectors, where heat pumps and combined heat and power (CHP) plants can be operated depending on the availability of electricity from intermittent energy sources (Bernath et al., 2019; Connolly et al., 2016; Lund and Münster, 2006; Lund et al., 2016a; Lund et al., 2016b; Mathiesen et al., 2015; Yuan et al., 2021). In addition to flexible demand, another way to increase the flexibility in the system is to use different types of energy storage. However, in order to identify optimal solutions for increasing the flexibility in the system, a holistic approach should be applied (Lund et al., 2016a). Sector coupling opens up the possibility of using energy storage across the sectors, allowing for the most efficient and lowest cost storage solutions in the system to be chosen. For instance, according to Lund et al. (2016a), pump hydro storage is not only the most expensive energy storage solution compared to the different types of thermal, gas and liquid fuel storages, but also the less efficient solution.

While the role of DH for achieving a more efficient and flexible energy system is pointed out in several previous studies (Connolly and Mathiesen, 2014; Lund et al., 2016a; Mathiesen et al., 2015), the role of the industrial sector has not yet been sufficiently researched. The industrial sector comprises several branches with different sub-processes that have different potentials to be operated in a flexible way (Golmohamadi, 2022; Shoreh et al., 2016), with the forestry and metal processing industries being considered to have comparatively high possibilities for flexibility (Söder et al., 2018). Sweden is a country with a well-developed DH sector (Werner, 2017)

and a strong and successful industrial sector that accounts for around 20 % of the country's GDP (International Trade Administration, 2021), and hence there should be significant opportunities to make use of flexibilities within these sectors in order to increase the share of renewable electricity production.

Sweden is part of a joint Nordic-Baltic electricity market with 15 bidding areas, and the Swedish system consists of four bidding areas (SE1-SE4) (Svenska Kraftnät, 2021). The price of electricity in each bidding area is determined by supply and demand of electricity and transmission capacity between bidding areas. Hence, there are different electricity prices in the different areas. In northern Sweden, the electricity price is the lowest due to high electricity production; in southern Sweden, the opposite is true.

The aim of this study is to get an understanding of how the industrial and DH sectors in Sweden perceive the potentials and challenges of flexible operations for their processes to enable an increased share of intermittent renewable electricity production and reduce the risk of capacity shortages in the electricity system. The following research questions guide the analysis:

RQ1: How can industry and DH companies be flexible in their electricity demand (and production) to respond to changes in intermittent electricity production (both surplus and deficit situations)?

RQ2: What are the perceived barriers to their flexible operations?

RQ3: What incentives would be needed for industry and DH companies to implement demand-side flexibility?

Method

In order to facilitate an in-depth understanding of how actors in the energy and industry sectors perceive the potentials and challenges regarding flexible operations of their processes, this paper uses an explorative research design. Empirical data were collected through interviews, and an interview guide was prepared based on the themes of the research questions. The interviews were conducted online using the digital tools Zoom and Teams, and followed a semi-structured format which gave the freedom to change the order of questions and to follow up on interesting answers (Kvale and Brinkmann, 2014). In total, 15 interviews were conducted in the autumn and winter of 2021–2022, and the length of the interviews varied from 45 to 90 minutes. The goal was to have respondents from energy companies located in different regions of Sweden and from different industry branches. Representatives from four energy companies, four pulp and paper mills, three metal companies, one food company, one foundry, one automotive industry and one chemical industry were interviewed. The majority of the industrial companies studied are energy-intensive, and as the pulp and paper industry and the metal industry together account for more than 55 % of industrial electricity use in Sweden (Swedish Energy Agency, 2022), the focus has been on these companies. Contact information was found on company websites and LinkedIn, and the first person contacted had the possibility to forward the request to participate to another person at the company.

The interviews were recorded and transcribed verbatim, and the transcripts were coded and categorised based on the themes of the research questions, i.e., potentials, barriers and incentives (Braun and Clarke, 2021). Assigning codes to words and phrases makes it easier to interpret, analyse and summarise the results of the empirical data.

Results

The interviews revealed several potentials, barriers and incentives for flexible operation of processes in energy companies and industries.

POTENTIALS

Energy companies

One DH company stated that it produces heat using heat pumps during hours with low electricity prices and stores the hot water in accumulator tanks. The stored water is then used during hours with higher electricity prices. However, a small reserve is always saved in the tank in case the other production facilities encounter disruptions. This is planned based on forecasts one day in advance. However, during cold periods, the heat pump is needed 24/7 and there is no potential to turn it off. By contrast, the heat pump does not run at all in the summertime since the demand for DH is lower and covered by heat from biomass boilers. The company has no CHP plants, but only produces heat. The heat pump and an electric boiler are currently operated as a flexibility service in the local electricity network. However, the electric boiler has not been used for the last 30 years or so, because it has been too expensive due to energy tax regulations. The consequence is that the wind power is wasted rather than being used to produce heat.

Another energy company had CHP in its system, but the current plant is very large and is only operated in winter when the heat demand is high, which limits the possibility to operate the production flexibly. However, the company plans to invest in a smaller CHP plant with higher controllability that can be operated for most of the year with the existing heat demand. The proportions of heat and electricity produced can be adjusted so that the plant can act as a flexibility service on the supply side.

When talking about the flexibility of future opportunities, one of the energy companies mentioned hydrogen as a possible flexible solution. In this case, hydrogen could be produced through electrolysis with renewable electricity in surplus situations, stored, and then used to produce electricity with gas turbines in electricity deficit situations.

Industry

It was stated that industry has the capability to be a flexible user if it has the potential for overproduction of intermediate products that can be stored and serve as a kind of energy storage (energy in products). This storage can later be used by subsequent processes if the upstream equipment is shut down. Another option is to operate the facility at maximum capacity for half of the day and at reduced capacity for the rest of the day. However, this also requires the availability of personnel, equipment and storage capacity, and associated costs.

Most pulp and paper mills produce electricity using turbines connected to their steam production, which are operated in a flexible way to meet the electricity price. Some mills have taken this further and installed an electric boiler which is operated in coordination with the existing bark boiler to produce steam, which offers a new opportunity for flexibility whereby the bark can be stored when operating the electric boiler. There is a trade-off between electricity and fuel prices, which determines when electricity generation is increased or decreased. Other demand-side flexibility options mentioned were operating bark crushers and woodchippers. One mill participated in the Frequency Containment Reserve – Disturbance (FCR-D) with its crusher as an active power reserve, meaning that the network company could turn off the crusher to balance the frequency in the electricity grid.

Electric arc furnaces in the steel industry are batch processes, and the production can be load-managed to some extent. However, it was stated during the interviews that this is easier for production facilities with ingot casting than for those with continuous casting. Additionally, heating, heat treatment and holding furnaces in the metal industry and the foundry industry, and drying ovens in the automotive industry can be turned off for a shorter period without affecting product quality. Smart systems, which can be used to plan and control heat-treatment processes based on available power, were mentioned as an enabler for this kind of flexible operation.

The respondent from the foundry industry also mentioned ventilation and evaporators as possible flexible processes. Investing in larger evaporation capacity (larger tank volumes) would make it possible to load-manage the evaporators. However, it is vital that any flexible management of ventilation does not affect the work environment negatively.

One interesting future flexibility solution that was discussed by the automotive industry is using used batteries from electric vehicles for energy storage. These batteries can be loaded during times of high intermittent electricity production and low demand, and then used as a back-up in times of electricity shortage.

There is a possibility for interchangeable use of hydrogen and liquefied petroleum gas (LPG) as fuels in heating and heat treatment furnaces in the metal industry. This allows for redundancy between two energy systems, where hydrogen is produced on demand in an electrolyser in the case of low electricity prices, while the electrolyser is turned off when electricity prices are high and LPG is used as fuel instead. Since the metal industry has a demand for oxygen, for example in heating furnaces with oxy-fuel combustion (Zhao et al., 2021), the oxygen from the electrolyser can be used to cover this demand.

The food industry has often a demand for cooling, and cold storage rooms can be turned off for one or two hours (especially during the winter) without affecting cooling quality. Furthermore, cooling with ice offers a possibility to produce ice during periods of low electricity prices. Another option that was brought up is the possibility to use two cooling techniques side-by-side: electric cooling machines and DH-driven absorption cooling. In this case, the company can switch between the two depending on the electricity price. Moreover, many processes have a demand for steam, and steam can be stored in accumulator tanks to secure a stable supply. The respondent

said that the company had thought about investing in a steam turbine and producing electricity, which could serve as a flexibility service. However, the company is investigating whether or not this would be profitable.

The interviewed representative from the chemical industry suggested low potential for flexible operations, because production is continuous and has a stable load profile. The main consumers of electricity at the company are pumps and compressors, and heating pipes in the winter to prevent freezing. The pumps used to transport the produced chemicals can be load-managed, and the running time can be shifted a couple of hours without affecting production. However, the company has started looking into the possibility of using hydrogen produced through electrolysis, which could allow for greater flexibility.

BARRIERS

Energy companies

Electricity prices and power demand are not always aligned, and prices can be high even if demand is low. One respondent described this as a barrier to a flexible electricity system, and pointed out the need for prices to follow demand more closely. The way the wholesale electricity market is organised, with gate closure time at 12:00, was raised as a barrier to a flexible energy system. An increased share of intermittent electricity in the system makes planning more difficult and requires more flexibility in the trading system so that the actors can submit their bids and offers later.

Uncertainties in intermittent electricity production forecasts were highlighted as a barrier to efficient electricity system balancing in a flexibility market. Moreover, the wind power producers are not interested in producing electricity without profit, which could hinder the generation of surplus electricity that can be stored in batteries and hydrogen, for example. Therefore, there is a need for business models that can handle this.

The high taxes on electricity¹ and high electricity network fees are considered barriers for using electric boilers and heat pumps in DH systems as a flexibility service. One respondent specifically asked for politicians to see the system as a whole instead of governing in detail.

Industry

A common barrier that was brought up was continuous processes that take a long time to start and stop, and sometimes each start and stop causes wear on the equipment. Customer trust is considered essential, and it is therefore important that any flexible operation does not affect the product quality or the ability to deliver products on time. Facilities that continuously work at maximum capacity and/or have limited warehouse space have few opportunities to be flexible. They cannot build up supplies that can secure production when equipment is shut down. This was brought up during interviews as a barrier. One industry company had previously allowed the network company to turn off certain parts of the production facility to bal-

ance the electricity system, but due to a high order intake the company has now blocked this flexibility service. However, it is investigating the potential to control its processes more dynamically, i.e., not only turning equipment on and off, but instead increasing and decreasing power demand.

Another barrier mentioned was a lack of competence within the company about how to manage and control flexible process operations.

There are perceptions among industrial companies that the network company will shut down electricity to the processes without notification and beyond the industry's control, and this has been a barrier to persuading industry to take an interest in providing flexibility services. Hence, there is a lack of information about how a flexibility service works. Moreover, one respondent was of the opinion that the process industry is conservative and does not want to have to consider external factors that may affect production.

INCENTIVES AND DRIVING FORCES

Energy companies

One incentive that was discussed was the possibility to have different regional regulations in connection with the four electricity price areas in Sweden. The respondent motivated this by saying that there are different regional conditions. The respondent asked for differentiated electricity taxes and network fees, and said that lower taxes and fees for heat production facilities in regions with large shares of intermittent electricity production could be an incentive for flexible operation of electric boilers and heat pumps in the DH systems.

Furthermore, it was mentioned during the interviews that policy measures such as greenhouse gas emission allowances for biogenic emissions could be a driving force for reducing heat production from biomass boilers, and instead introducing flexible production of heat from intermittent renewable electricity in combination with heat storage.

Increasing the time-resolution of measured electricity consumption was mentioned as a driving force for a flexible energy system. One energy company said that it had initiated work to measure values every 15 minutes instead of the current hourly values. In the case of highly fluctuating electricity prices, this would enable the customer to pay more accurate electricity prices and not an average. The customer would then have the incentive to reduce electricity consumption on demand during time of high electricity prices and see the results on its bills. The respondent pointed out that this must be combined with information, communication, control systems and proper agreements. Another incentive mentioned was customised electricity contracts with individual pricing based on demand and maximum allowed consumption. Furthermore, one respondent raised the issue that all consumers must currently have the same security of electricity supply. If, instead, different contacts have different levels of supply security, the flexibility in the energy system would increase. The respondent was keen for decision-makers to have knowledge about the energy system, the ability to see the wider picture and the courage to make the necessary decisions. Further, the idea of a standardised procedure for flexibility markets was raised. For example, common price models would make it easier for different actors to participate with flexibility services.

1. In Sweden, there is a tax on electricity use of SEK0.36/kWh (excluding VAT). However, some businesses are entitled to varying levels of tax refund. The heating sector is not among them. (Vattenfall, 2022. Energiskatten 2022: Detaljerad information om energiskatt på el (Energy tax 2022: Detailed information about energy tax on electricity) [In Swedish].)

Trading flexibility in a flexibility service market requires the market to be trustworthy. It was highlighted that the market must be used continuously so that stakeholders rely on it and consider it worth participating. Additionally, it is vital that the load provided as a flexible service is available when the network needs to activate it. Moreover, there is a need for tools that can provide more accurate long-term forecasts of intermittent power production.

The interviews revealed the need to clarify responsibilities and roles, and for more proactive decisions from the government. Without knowing what will apply in the future, the companies are not keen on participating with flexibility which may interfere with their production and affect profits.

Industry

Economic gains are the main driving force for flexible operations. A variable electricity price was given as a reason for load management. However, just-in-time deliveries to customers are prioritised, which sometimes hinders load management. Compensation from the network company for providing demand response service was also mentioned as an economic driving force. There are different business models for this, and two projects are currently testing flexibility markets in Sweden: the EU-financed Horizon 2020 project CoordiNet (CoordiNet, 2019) and the sthlmflex project owned by Svenska Kraftnät (Svenska Kraftnät, 2022). Respondents highlighted that the economic gains for providing a flexibility service in a market must be at a level that compensates for any loss of income or higher expenses. According to one respondent, an electricity contract where the company was assigned more power supply in return for providing electricity flexibility on demand could be a driving force. This would enable the company to increase production capacity.

One respondent said that they currently plan their production far in advance, but that they may be forced to have shorter planning periods in the future to meet rising and fluctuating electricity prices. In addition, high-resolution monitoring of electricity consumption would be needed. This would enable and incentivise load management in industry.

The potential to produce renewable hydrogen on demand onsite through electrolysis and to use this interchangeably with LPG in heating furnaces can be implemented without the need for any additional storage or distribution pipelines. Moreover, this solution contributes to a national distributed hydrogen system and creates a new business model where hydrogen can be sold at profit to external actors. This new business model can also facilitate an increased production capacity of core products at a metal company, since increasing hydrogen production also increases the amount of oxygen produced that can be used inhouse, for example in furnaces. Furthermore, excess heat from the electrolyser and steam from the furnaces² can be sold to customers with a demand for heat, such as DH companies.

Goodwill and demand from customers were other driving forces for flexible operations that would enable a larger share of renewable energy, because the companies could profile themselves as fossil free. Regulatory demand from the government was also mentioned as a driving force, and one respondent said

that they would be more likely to be motivated by a stick than a carrot. According to the respondent, one incentive could be the network company demanding that its customers provide flexibility.

Other driving forces mentioned were raising the issue higher up within the company's organisation and issuing information to relevant personnel. Additionally, implemented demand-side flexibility solutions could serve as good examples and be incentives for others to follow. Grants for performing pre-studies and pilot studies are also a driving force, but the respondent said that the application forms are often complicated and take too long to fill in, which could deter the company from applying. In large corporations, one solution could be to have a central function that summarises and interprets legislation and lobbying, and searches for grants that the company can apply for. Moreover, respondents asked for a national energy centre that coordinates targeted research and helps companies to implement systems and solutions.

Cooperation between actors was highlighted as an enabler and a driving force for solutions that demand skills and knowledge from different areas of expertise and/or large investments. One such example is the implementation of electrolysers for hydrogen production, which also creates synergies between different hydrogen consumers (industry, transport, etc.). Another is industry and municipalities that work together to map and investigate opportunities and prerequisites for load management and increased use of excess heat, and to lobby for increased grid capacity.

Software that can automatically balance the electricity system with demand response was highlighted as an enabler for a flexibility market. There are flexibility service firms that provide software platforms with real-time monitoring and balancing of electricity supply and demand, which can help companies to participate in demand-side response services. These flexibility service firms were mentioned as a driving force for flexible operations in industry. The firms provided knowledge, and one respondent highlighted that this was also an economic question as the equipment and software required no initial investment and was instead subtracted from the income received when processes were shut down by the network company. They considered this to be a profitable solution, and had not noticed any effect on production.

Several respondents raised the concept of smart systems as an enabler for a flexible energy system. One respondent had a vision of a future smart energy system with sector coupling, where artificial intelligence (AI) worked continuously to improve the accuracy of predicted electricity supply and demand to balance the system on demand.

Discussion

Due to increased electrification of the industrial and transport sectors, as well as future population increases in Sweden, problems with bottlenecks in the network may occur. Electricity grid capacity challenges can arise locally and regionally, which would compromise supply security in the country. These capacity problems, together with increased intermittent electricity production, will present great challenges for our future energy system. Historically, the bottleneck problems have often been addressed by increasing the capacity of the network or

2. When hydrogen is used as fuel, water is produced in the combustion process.

by increasing the supply capacity (i.e., by building new power plants) in the regions where the supply is compromised. Both strategies usually involve considerable investment costs. Demand-side management, i.e., using demand-side flexibility and storage solutions across the sectors, may be a less expensive solution. However, this solution requires the development of new business models and new markets for flexibility service in the electricity sector.

Designing an organisational system for managing demand-side flexibility is challenging because it requires cross-sectorial and technical integration, as well as involving several stakeholders (e.g., energy corporation, network owner, core network operator, industrial companies, municipalities, different associations, and software and hardware developers) who work at micro and macro levels. In order to ensure the successful implementation of demand-side management and to avoid sub-optimisation, it is necessary to understand interactions between the involved stakeholders. The choice of which stakeholders to involve and the communication and operating rules should be designed and managed based on the local conditions. Researchers also play an important role, not only as initiators of the strategy but also to develop incentives and political frameworks. Furthermore, researchers and software developers should aim to develop design principles and control solutions which could be used in different local conditions (i.e., are applicable in different industrial and DH companies) and with different types of hardware. The cooperation between the electricity user (or prosumer) who provides the demand flexibility in the network and the network operator can be contractual, voluntary or price-based. Price-based demand response can be a highly effective solution. Even though it is the customer (or prosumer) who has complete control over electricity use, critical peak pricing (during the periods with low intermittent electricity production or demand peaks) and “time of use” tariffs may be an efficient way to encourage the customer to adapt electricity use (and production) depending on the situation/requirements in the system.

An important barrier raised during the interviews was that flexible operation of industrial processes could affect the ability to deliver on time, which could lead to the company losing customers. Hence, agreements where customers accept delayed deliveries, motivated by power shortages in the electricity system, could be a solution to overcome this barrier. Another solution is to improve customers’ overall knowledge and awareness about the challenges related to the intermittent electricity production and the possibilities to overcome these challenges by adapting production within the industrial sector. However, this solution requires engagement on a more national level. Economic incentives (e.g. financial compensation for shifting electricity consumption in time) can also be a good strategy to encourage industrial companies to provide flexibility. However, previous research (Golmohamadi, 2022) has pointed out that the demand response incentives should be adapted to each individual industry, because financial losses or revenues from shifting or curtailing electricity consumption differ between companies. Hence, the financial compensation should be based on the characteristics of the company.

Power-to-gas was raised by several of the respondents as an enabler for a more flexible electricity system. Previous research (Li and Mulder, 2021) points out that the profitability of a solu-

tion with a power-to-gas plant combined with hydrogen storage and hydrogen-fired power plants is correlated to the carbon price, and at low carbon prices conversion efficiencies of electrolyzers have to be increased and installation costs reduced in order to be profitable.

The results indicate that energy companies and industry in Sweden have started to investigate possibilities to operate their processes more flexibly. However, there seems to be a lot left to do in this respect. The ongoing flexibility test markets may possibly contribute knowledge about how to coordinate and manage successful flexibility services. Good examples could lead the way, incentivising others to follow. There are several initiatives of local flexibility markets in Europe (Accenture, 2021), and Directive 2019/944 of the European Commission presents common rules for electricity markets including incentives for flexibility procurement.

Conclusions

There are several options for energy companies and industry to operate their processes more flexibly. However, the potential is, to a large extent, not used today. Energy tax is an economic barrier to flexible use of heat pumps and electrical boilers for producing heat in the energy sector. Industry strives to maximise profit and hence minimise the time that materials and goods are stored. That means that the most efficient way is to have a continuous material flow and to avoid investing in overcapacity. This production concept within industry is a barrier to flexible operations, as some processes cannot be shut down without affecting other processes in the value chain. Moreover, continuous production that runs at maximum capacity is more challenging to operate in a demand-response mode, since no stock can be built up at times of surplus in the electricity system.

There is growing interest in hydrogen produced through electrolysis using renewable electricity, but to allow for new electrolyzers to be built that can serve as flexible electricity users, there may also be a need to increase installed electricity production capacity.

Successful implementation of flexibility markets requires that the actors providing demand-side response services receive compensation that generates a profit and serves as an incentive to make the necessary investments and/or change the way they operate their business. The required compensation may differ depending on local conditions (related to the industrial processes and the conditions in the network). Furthermore, there is a need for regional and national regulations with a holistic approach that contributes to a sustainable and flexible energy system.

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