INNOSOFC

WP2 Fuel cells as a part of intelligent energy infrastructure

Deliverable 2.2. Future scenarios

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Executive summary

What will be the energy mix in the medium to long term and what role can the C50 Fuel cell CHP play?

This report identifies relevant trends that will impact the business opportunities. Europe's energy supply and demand are changing at a rapid pace. Growing renewable capacity is leading to disruptive effects on energy markets, where investments in centralized power plants are becoming very uncertain.

On the other hand, customers are becoming more demanding to reduce their carbon footprint as a result of their Corporate Social Responsibility and compliance with local legislation. These developments form a good breeding ground for decentralized , ultra-efficient and reliable power plants, which can accommodate intermittent sources. The C50 is well-adapted to match these needs.

With the commitment of European Member States to the CO_2-reduction goals of the Paris Agreement, we expect that the paradigm shift, which is already taking place, will increase in pace. To substantiate these changes, this research has investigated developments four categories: end-users, fuel markets, electricity markets and energy policy. The results have been quantified in an economic assessment of three use cases:

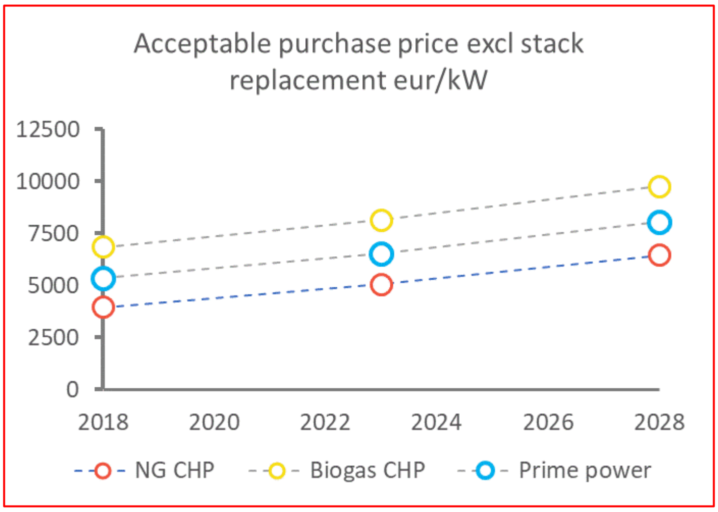

Figure 1: Economic impact analysis for BAU assumptions

The overall trend for all three cases is that the revenues earned by end-users will increase by 20% towards 2023 and up to 50% by 2030, mainly due to higher electricity prices including taxation. For specific Member States these increases might be even greater as a result of nuclear and coal phase out. There are many trends that add in positive way to the business outlook, not only in the business case but also in a general interest in equipment that will reduce the carbon footprint of end-users as well as countries.

However, it must be noted that the general perception of end-users might be biased towards all-electric solutions based on heat pumps and solar panels. This issue needs to be addressed through proper marketing on current and future effects on CO_2, infrastructure and system costs, perspective on renewable fuels and complementary role in to all-electric concepts.

Since biogas CHP and prime power are premium markets, we recommend to focus on these applications and keep track of countries with attractive market and policy conditions for the C50. These countries include Germany, Italy, Greece, UK, Netherlands.

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1 INTRODUCTION

1.1 Background

The energy landscape across the EU is changing very rapidly. In the past, energy production was centralised and fossil fuel–based. Smart grids, solar panels, and the "Negawatt" (a unit of power representing an amount of energy saved) are changing the way the energy system – and the economy – works. Consumers were passive. Today, energy is increasingly produced by decentralised renewables and consumers are active and engaged. However, the challenge to come to a 80% reduction of CO_2 emission by 2050 is very big (see figure 1) and will require a substantial increase in renewables and energy efficiency, up to 35% in 2050 from amongst others Fuel Cell CHP .

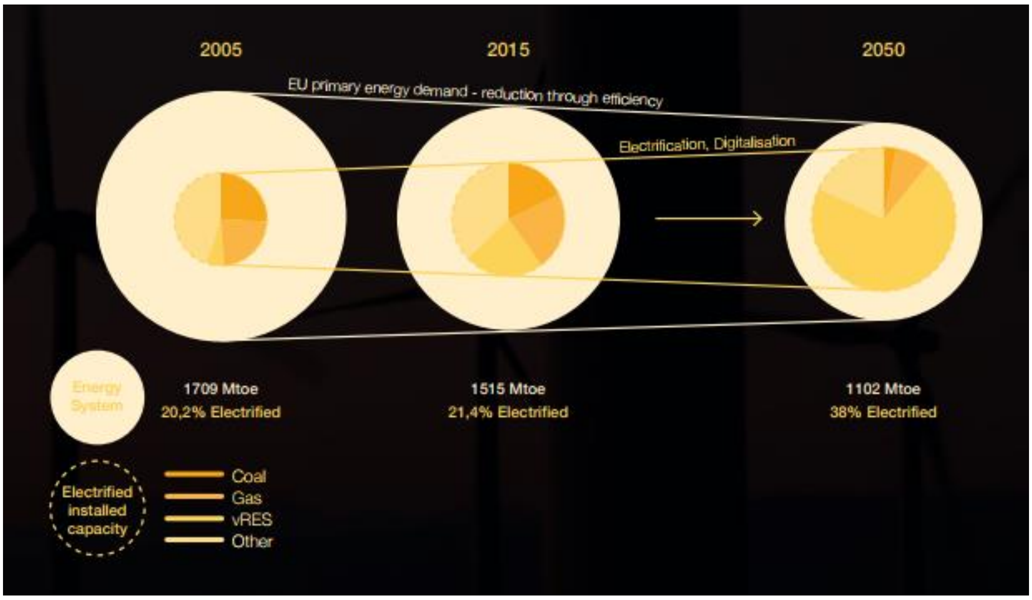

Figure 2: Change in EU energy system towards 2050. Source: [1]

Some key developments have already impacted the energy market. Costs of renewable capacity (wind, solar) have fallen dramatically and are likely to drop even further. Expected evolution of energy storage technologies as well as increased adoption of energy management systems further drive deployments of decentralized solutions at the consumption end of the chain. While the above factors complemented with regulatory interventions have made distributed generation more attractive as a solution, they have also created uncertainty around investments in centralized generation requiring long planning, construction and large upfront investments with long pay-back times. Navigant Research forecasts new additions to distributed capacity additions to surpass additions to central generation globally in 2018 (Figure 3). While much of this new capacity is still based on legacy technologies and fossil fuels, the clear shift represents an inflection point for energy systems.

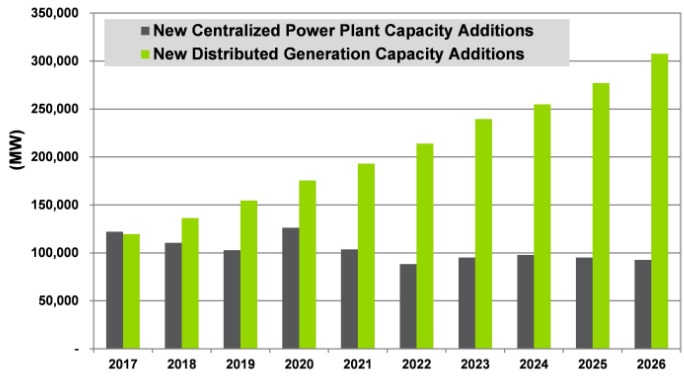

Figure 3: Annual installed centralized vs Distributed Power Capacity, World markets. Source: [2]

These developments have led producers and users of energy coming to new perspectives on what role to play in the future energy system. Large energy producers such as RWE and E-on have established dedicated business units to pursue new market opportunities in the future energy systems, such as a local energy aggregator and facilitator. This is a radical shift from producing and selling high volumes of electricity and gas. End-users on the other hand are working to lower their energy bills and reducing the carbon foot print. A change of consumers to so-called prosumers is well underway, where end-users are playing a very active role in the new energy system. Consumers expect heat, light, mobility and comfort as a modern convenience, not just kilowatt hours. And they expect these services at a decent price, available on demand and responsibly produced.

To address all these developments and to reduce the uncertainties for the development of the C50 SOFC CHP system that comes along with these changes, a separate work package has been created to analyze these topics.

1.2 Research objectives Task 2.2

Work package 2 is divided into three work tasks. Task 2.1 is focused on defining the optimal application of the C50 fuel cell system Task 2.2 contains an analysis of future trends and their effect on SOFC application, and finally Task 2.3 focuses on the techno-economic analysis of SOFC systems. This deliverable contains the report for Task 2.2: Future scenario's.

Task 2.2 contains analysis of future scenarios in both short term (2-5 years) and medium term (5-10 years). In this work task, the effect of future trends in energy policy and economics on SOFC systems is analyzed. This will include not only the expected bandwidth of economic parameters such as future energy prices but also changes in demand of end-users and legal expectations concerning permits, network codes and government support.

1.3 Scope

In a general sense, the scope is geographically defined by the EU27 countries. But in order to assess impact of renewable policies a number of Member states will be observed more closely: Germany, UK, Italy, France and the Netherlands.

The timeframe is both short term (2-5 years) and medium term (5-10) with 2018 as the starting point.

2 METHODOLOGY

The energy markets are changing quickly throughout the EU Member states. In this task, we want to objectify the relevant developments and determine the impact on market possibilities for the C50. Therefore, this research will be based on external reports where possible, challenged and complemented with experiences from Energy Matters, Convion and ENEA.

Approach

The analysis will be broken down into the following steps:

1. The starting point for the future scenarios are the end users. What do they want and what is their future role in the energy system?
2. The second point is to describe the impact on the most relevant business drivers that were discerned in WP 2.1. This includes both economic parameters as well as the influence of stimulating policies. The following four categories will be analysed:
    a. End-users
    b. Fuel markets
    c. Electricity markets
    d. Energy policies on energy taxation & incentives
3. The third step is to describe other relevant factors for the implementation of the C50
4. Where possible, these effects will be quantified and the impact on the acceptable costs levels will be calculated for three different use cases: Natural gas CHP, biogas CHP and back-up power.
5. Bring together both the quantified as the non-quantified conditions and draw conclusions on the best use cases, systems configurations, interesting markets

3 END-USERS

End-users, whether it be private companies, energy companies or government bodies, are crucial for the implementation of the C50. As the total energy system changes, the role of end-users is changing from retail clients to active involvement as prosumers. The EU actively encourages this development.

This chapter describes the most relevant factors that drive end-users in their decision making on their energy supply. A worldwide study on this topic reveals the following significance of several factors:

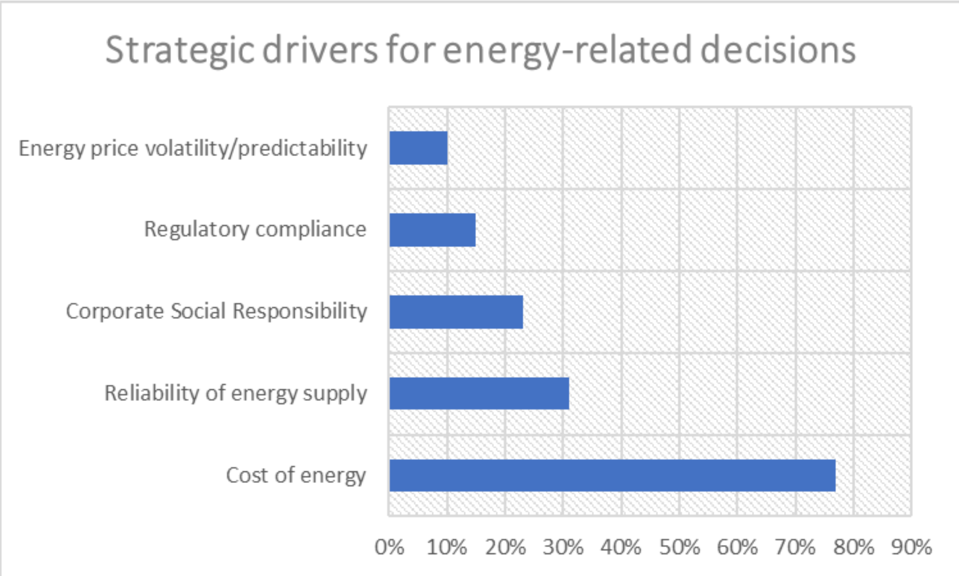

Figure 4: Worldwide Influencing factors for energy related decisions. Source: [3]

The focus on cost of energy is not surprising but Figure 4 indicates that other drivers are important too. We will describe relevant developments at end-users on the following three topics: corporate social responsibility, reliability, and predictability & affordability. In addition, a paragraph is dedicated to the upcoming of smart grids. Regulation & compliance will be covered in chapter 6.

3.1 Corporate social responsibility

Shifting paradigm

Fossil fuels are a finite resource, linked to climate change and air pollution. Even though energy production is still mainly fossil fuel based, the public opinion of fossil fuels is shifting to the negative. Coal has the worst reputation: it has the highest impact on climate and air pollution and the worst mining conditions of all fossil fuels. The increasing negative public opinion of mainly coal and nuclear power generation, may push them out of the energy mix. Meanwhile, renewable energy technologies are becoming more mainstream and contributing to clean generation. For example, wind farm participation and solar roofs are becoming increasingly popular. Producing your own, low carbon electricity and heat on site using natural gas, or even fully sustainable heat and electricity when using biogas, can enable businesses to become more sustainable while using existing infrastructure.

Both public bodies and private companies are starting to take more initiative on a better environmental impact and lower carbon footprint. Public bodies are usually driven by national or local policies and are attractive customers. Lighthouse projects applying new energy concepts in practice are often executed by public bodies as a result of those policies. Moreover, ambitious targets are set to implement renewable energy since the sector wants to lead by example.

Private companies are also starting to take this issue more seriously. Driven by a better informed and more demanding customer, private companies have a growing attention for the concept of Corporate Social Responsibility (CSR). The importance of the public perception of the company's effects on the environment has been acknowledged by the industry. A worldwide study shows that 91% of the consumers expect firms to operate responsibly to address social and environmental issues. A similar share of the customers state that they have a more positive image, are more likely to trust and are more loyal towards companies supporting those issues [4]. Corporates seem to acknowledge that public perception will become even more important in the coming years. In a global CEO study, a quarter of the CEOs that were interviewed believe that addressing broad societal issues is crucial for a business to be successful [5]. The number increases to 44% when CEOs consider what the importance of this aspect will be in five years. This is in line with the outcome that 70% of the CEOs state that corporate responsibility will be a core element in their business decisions in 5 years compared to 62% at the moment. More and more companies are therefore implementing a CSR strategy.

To a lot of companies the transition towards clean energy usage is an integral part of their CSR goals. A growing group of multinationals has announced that all their electricity and heat will be produced 100% renewable in 2020. The initiative RE100 unites more than 100 influential businesses committed to only consume renewable electricity. The costs involved of changing to a fully renewable energy supply are of less importance for companies striving for these goals. Also, in their quest to become the first fully renewable company they tend to take more risks using innovative technologies. Thus, these companies provide attractive prospects for the use of fuel cells.

Integrating more renewable energy into the energy system comes with an enormous challenge to match the renewable energy generation with the energy requirement. Corporates focused on becoming 100% renewable need to face this challenge, especially when they take into account the broader picture of an resilient energy system. This provides another opportunity for the use of fuel cells. Efficiently thermally matched on-site mCHP facilitates increasing amounts of intermittent renewables in the energy system.

Moreover, there is a growing tendency in policy actions to focus more on "clean" energy than "green" energy, especially in view of air quality issues in urban areas. Several studies point to significant health impacts caused by urban air pollution (NOx, SOx, particulate matter, etc.), outweighing even traffic accidents [6]. The intrinsically clean operation of a fuel cell CHP system is a great asset in this respect, also considering the contribution to air pollution caused by combustion-based heating systems in cities.

However, in this case it is crucial what the public perception is on fuel cell technology and if it is considered as a clean energy technology. Companies implementing renewable energy sources driven by CSR motives want to be able communicate a green image to their potential customers. The CO_2 reduction of natural gas fired CHP differs per Member state through the differences in the current and future generation mix. As a result the perception of the effect on the carbon footprint may vary significantly. End users are usually not well informed on these issues and in many cases have a perception of a fully renewable (future) grid, in which case they will be less inclined to invest in natural gas fired power generation in the long term. This poses a risk for the INNO SOFC system. This risk may be mitigated either through right marketing on how the C50 adds to an affordable and energy efficient system or otherwise by contracting green gas (see 4.3.1 Green gas certificates)

3.2 Reliability

The reliability of the EU high voltage grid is very high. Lower voltage grids are reliable too, with the occasional faults and temporal blackouts. Due to increased interconnectivity and cross-border cooperation, the stability of the grid will likely not decrease. However, the increasing cost of a power outage for all sorts of businesses makes that reliability and energy security are a critical point of concern for some of them. Of course this is already true for prime power such as data centers or back-up power applications. Figure 2 shows that for 31% of the businesses reliability is an important driver for decisions on their energy strategy. Although this share might be lower for the EU, as the grid is significantly more stable than elsewhere in the world, it represents an important selling argument as well as it may provide an added value for the business cases.

3.3 Predictability and affordability

Cost of energy is the most prominent driver for energy-related decision-making. This was a barrier to the renewable energy procurement for a long time. However, due to major cost reductions in the last couple of years, clean energy sources have the potential to deliver financial benefits. Renewable energy is more and more seen as a business opportunity because it offers the possibility for long-term cost saving benefits compared to traditional energy procurement. The extent of these benefits depends on the selected technology, the regulatory environment and other prerequisites. The ability of the C50 to offer financial benefits depends on the market and use case. These are described in workpackage 2.1.

Another financial benefit relates to the volatility of energy prices and the predictability that renewable energy can offer regarding energy costs. In 2012 10% of all businesses stated that price predictability was an important driver regarding their energy strategy. It is likely that the importance of price predictability has increased even further since then due to concerns that implementation of renewables, the coal phase-out or carbon taxes may lead to price rises. The last couple of years more and more companies try to create energy price predictability through access to a mix of alternative energy sources.

A recent development in the market is the introduction of Power Purchase Agreements (PPAs). PPAs are a way for corporates to make a deal with power generators for the power produced from one or more specific facilities. For off-site projects the physical power produced by the generation site is not delivered directly to the consumption location but channeled through the existing power grid. Since output of renewable generators is not likely to be in line with the demand, mismatches are balanced by the grid. PPAs could include some kind of "sleeving" contract with the utility company about the way the intermittent electricity output of the generation facility is credited against the electricity demand

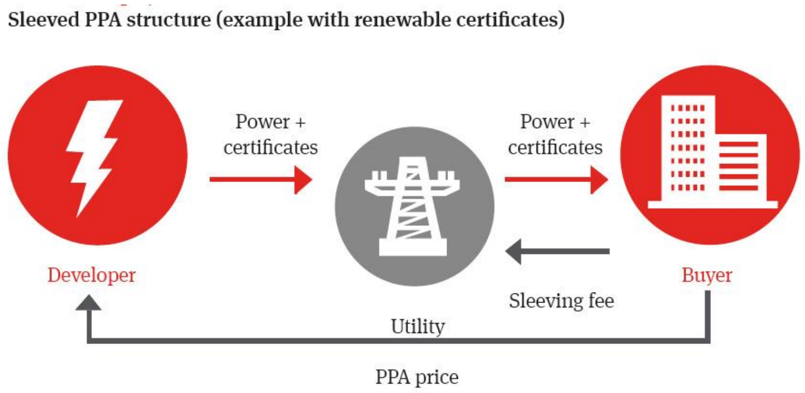

Figure 5: Contract structure PPA. Source: [67]

of the company. An organization can also choose to invest in off-site generators before construction. In those situations an organization has the opportunity to take some or all of the power produced via a PPA. Without a PPA, a level of price stability is reached since extra consumption costs due to an increase in the electricity price will be offset by higher revenues from selling power of the project to the market.

Besides procurement via off-site renewable projects, an organization can also obtain renewable energy via a project on or nearby its own site if the location is suited. This option tends to carry the highest reputational benefit and offers more energy security compared to off-site renewable energy investments. The number of on-site renewable projects are increasing rapidly. In the UK capacity of on-site renewables increased from 4.7 GW in 2012 to 12.8 GW in 2016 with solar photovoltaics responsible for 44% of this capacity in 2016 [7]. The intermittent character of solar photovoltaics is a limitation for energy price security. In this way dependency on market prices remains significant even when capacity would be sufficient to cover energy demand.

Diversifying the energy mix by PPAs or on-site generation can lead to a reduction in the exposure to volatile and rising energy prices. However, the mismatch between the output of the generators and the organization's energy requirement is a complicating factor for energy price reliability. A small scale CHP that matches the thermal needs of a site has the potential to balance intermittent power from wind and solar. Use of small scale CHP could therefore offer more energy price security, especially in the case of on-site biogas production. The trend that end-users will have a larger focus on energy price volatility and reliability can have a positive impact on the business case for SOFC systems.

3.4 Smart grids

End-users are turning into prosumers and local grids are starting to be optimized and locally balanced in so-called smart grids: local networks with flexible users and producers. Obviously, the C50 can play a central role in the use of these smart grids, as a reliable and flexible component in conjunction with energy storage.

There are a number of key changes that can lead to the implementation of smart grids:

- Quick growth of decentralized prosumers (currently mostly solar panels)
- Digitalization of the energy sector and development of smart homes & businesses
- Potential of demand side management to contribute to grid stability and lowering of system costs
- Optimization of energy efficiency at end-users through usage of DC power
- Roll-out of smart metering and related services

This development is being recognized throughout Europe as a mean to facilitate the use of national and local renewables at lowest system costs. It involved a multitude of players and therefore requires an intelligent system control that enables the most effective operation of all assets involved. This is depicted in Figure 6.

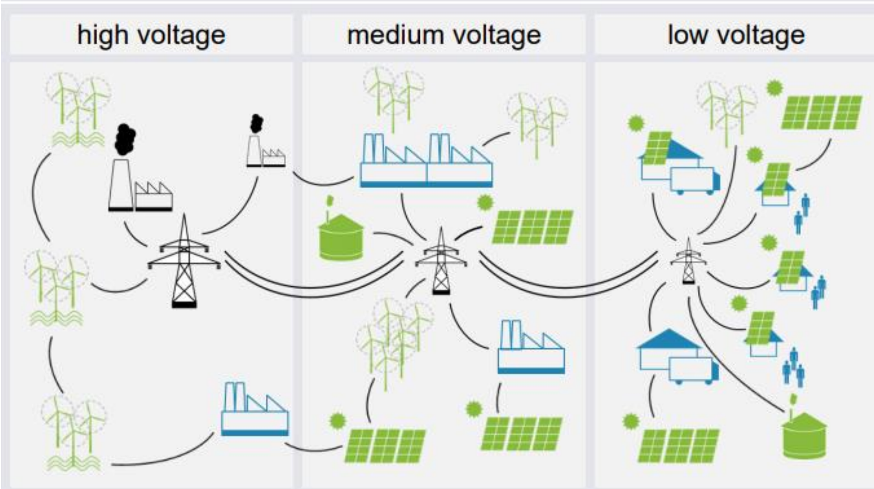

Figure 6: Old and new electricity system. Source: [8]

Up to now these developments have been mostly performed in R&D and demonstration projects focusing on the various aspects of smart grids. Figure 7 shows a large number of projects that have been realized across Europe. The number and scale of the smart grid projects has been increasing the last couple of years. A recent European smart grid project InterFlex includes six large demonstration site in Germany, Denmark and France to explore ways to optimize electric power systems on a local scale. The largest smart grid in Europe will be rolled out in Rotterdam in the next three years. During the course of this project, 20,000 households and several distributed energy generation facilities are to be connected to a smart grid.

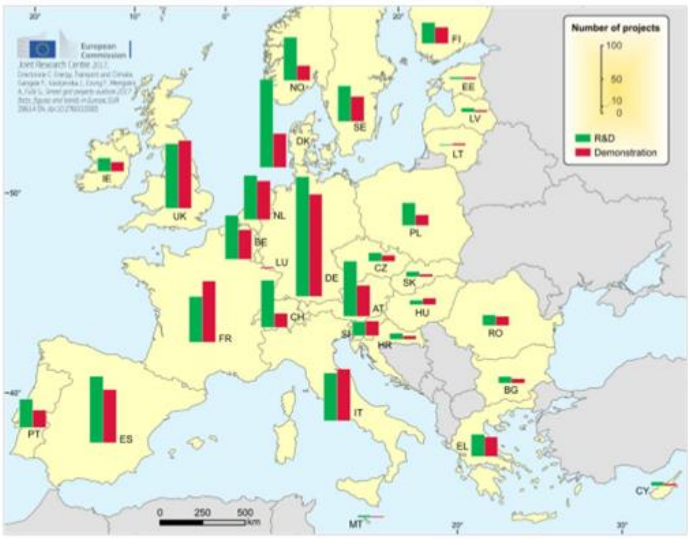

Figure 7: Number of smart grid projects per country. Source: [66]

Smart grids are therefore starting to form an important part of the context where end-users have to reflect on their strategic energy related decisions what they may benefit or add to the system, perhaps giving a greater value than what could be derived currently from national market mechanisms.

3.5 Conclusion end-users

For the future implementation of the C50 we see the following relevant issues at end-users:

- A growing awareness of the urge to reduce carbon emissions among individuals and organizations. For businesses, the concept of corporate social responsibility is increasingly determining business decisions. This will lead to a higher demand for renewable and low-carbon solutions.
- Growing relative costs of grid failure will lead to a strengthened positioning of the C50's reliability as a selling argument.
- A growing number of companies are mitigating risks associated with energy price volatility and reliability through the use of off-site PPA's, where specific (renewable) energy sources are contracted to limit energy costs. The use of on-site CHP systems could lead to even more energy price certainty.
- Smart grids are gaining momentum and are likely to incorporate components with characteristics suited for the C50: highly efficient and reliable, perhaps DC powered webs.

4 FUEL MARKETS

In this chapter, we discuss the relevant factors on the fuel markets, focusing heavily on natural gas and biogas as the main sources of energy for the C50. Fuels like heating oil, diesel or uranium are left out of the scope as they are unlikely to be used as a fuel.

4.1 Coal

Coal is the most abundant source of fossil energy around the world and is widely used for power generation and within the process of iron and steel production. In terms of energy, the world-wide coal consumption in 2016 decreased by 1,9% or 105.7 Mtce, whereas in OECD countries the decrease in coal consumption was as high as 5,3% compared to 2015. Overall, the global production declined by 458 Mt in 2016 compared to 2015 as is shown in Figure 8 [9]. According to DNV-GL, the decline in coal production shows that coal use has already peaked and coal consumption will drop by roughly 75% in 2050 compared to current levels [10].

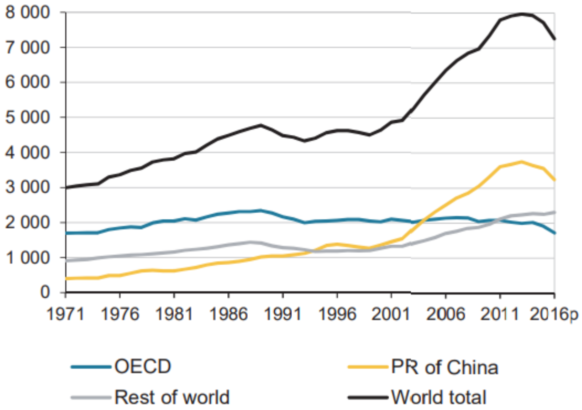

Figure 8 – World total coal production (Mt) Source: [9]

The current wholesale coal price in $/Mt is slightly above the coal price of 8 years ago. The price peaked in 2011 after which a decline started due to oversupply [11]. The decline was interrupted in 2016 by a rapid growth caused by a drop in production in China which led to an increase of their coal import. Moreover, a strike of miners in India led to problems in the coal industry in India [12]. The World Bank expects that this is not a long-term trends. It predicts in its commodity forecast report that prices after 2017 drop to 2015 levels by 2020. After 2020 prices will grow slowly with a few percent a year [13].

Figure 9 – Historic coal prices ($/Mt) Source: [11].

Use of coal without Carbon Capture and Storage (CCS) isn't seen as a long term option in renewable markets. More about current coal phase out efforts is described in paragraph 5.1.4. Currently there is no carbon capture unit installed at a coal plant operating on a commercial scale while being cost-effective. Due to the expected phase out of coal, large investments in the developments of coal CCS are not to be expected. A recently published report, the Global Warming Policy Foundation claims that the prospects for coal CCS in Europe are very limited. The advantages of natural gas can only be offset if the prospective cost of coal CCS were about 25% of current estimates [14].

Gasification of coal might be an alternative since the capture of carbon dioxide is easier and thus more commercially viable. Furthermore, gasification allows to valorize many solid fuels, including solid waste (organic and non), for the production of syngas ($CO + H_2$) The clean coal route has been actively been pursued in the U.S. under the SECA program of the Department of Energy, where SOFC is seen as a key solution for using the product gas.

4.2 Natural gas

The C50 is purposely built for the use of natural gas because natural gas is a widespread and affordable fuel across Europe and because an SOFC can obtain a very high electric efficiency due to its internal reforming. As natural gas is one of the most important cost drivers for the C50 business case it is of great value to have insights into the historical, present and future natural gas market.

Global consumption and European trends

Natural gas is still widely used throughout the world for power generation, heat production and as a feedstock for a variety of processes and in 2016, consumption was as high as 3630 billion cubic meters (bcm), see Figure 10 [15]. The IEA expects that the global annual gas consumption will increase with 1.6% per year until 2022. This increasing gas demand is expected to be primarily caused by the people's republic of China with of share of 90% of this increase [16]. The increase in gas consumption means that the global volume of consumed natural gas will rise from 3630 bcm in 2016 up to 4000 bcm in 2022.

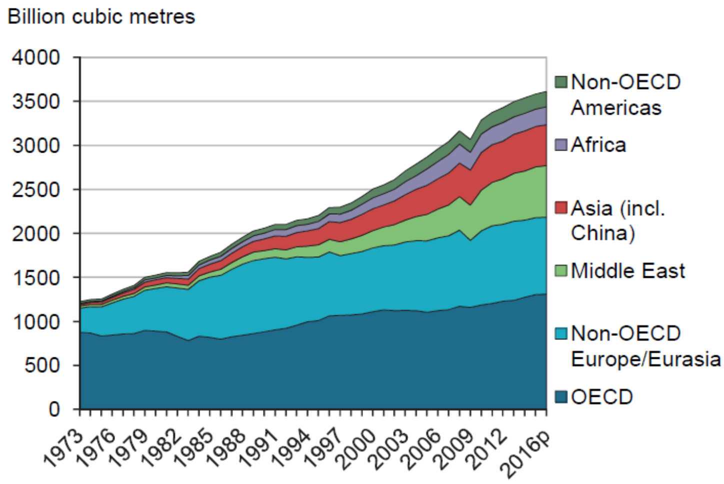

Figure 10 - World natural gas production by region. Source: [15]

In Europe, which consumed around 14% in 2016 (523 bcm) of the global consumption [17], the gas demand has been declining between 2010 and 2015 but has since increased for two years in a row now. Several factors for the increase of gas consumption have been indicated by the IEA; a decline in gas prices, an increase of coal prices, nuclear outages in France and the decommissioning of coal fired power plants in several countries. Furthermore, due to the carbon floor price in the United Kingdom the power generation from gas fired powerplants rose. However, up until 2022 the IEA does not expect an increase of natural gas consumption in Europe as the share of renewable electricity increases and the growth in electricity consumption will be limited [16].

4.2.1 Domestic production and imports

Within Europe, both the United Kingdom and The Netherlands face a decrease of their domestic natural gas production. In order to compensate the decrease, Norway increases its production which is presented in Figure 11. Not only Norway is compensating the decline in natural gas production within other EU countries, also Russia and Algeria are increasing their share, via pipeline trading, within the European gas market [18]. Rising dependency on import will put pressure on the gas price.

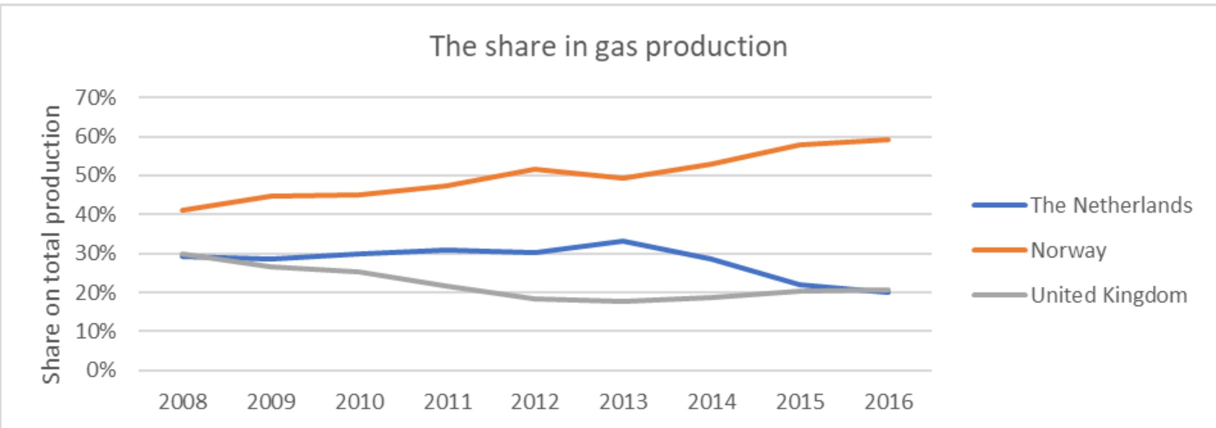

Figure 11 - Top 3 natural gas producing countries in Northwest Europe. Source: [19]

Developments in LNG

An abundance of natural gas in countries such as Qatar, Australia and Malaysia, a global shift from coal to natural gas and natural gas import diversification results in a still growing consumption of LNG as is presented in Figure 12.

Globally, natural gas accounts for approximately 25% of the global energy demand, 10% of which was supplied as LNG in 2015 [20]. In order to meet the continued demand for LNG, sufficient liquefaction capacity is essential. The IGU reported that the global liquefaction capacity grew by roughly 10% in both 2015 and 2016 to a total of 340 million tons per annum (MTPA). Worldwide, the proposed liquefaction capacity is aimed at 879 MPTA. Furthermore, the LNG shipping fleet grew with 31 vessels to a total of 439. These numbers indicate that LNG is expected to gain an increasing share in the global energy demand in the years to come. For Europe, the IGU expects that LNG imports will increase over the next two years.

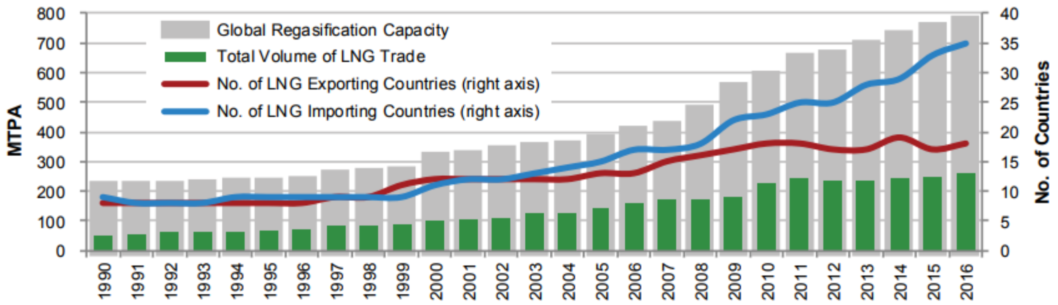

Figure 12 - LNG trade volumes, 1990 -2016 Source: [21]

However, there are some doubts that the LNG capacity will not keep pace with demand, which might lead to a tighter gas market after 2020. This is depicted in Figure 13.

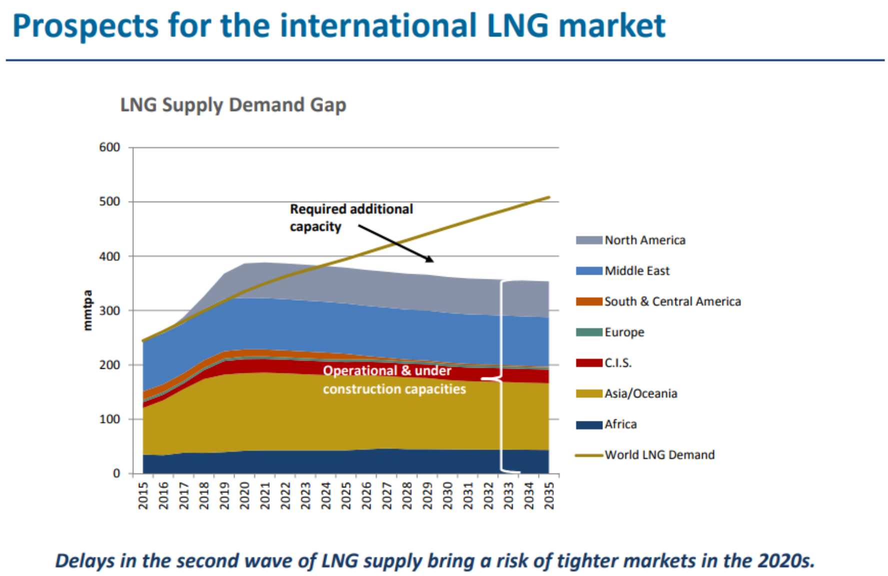

Figure 13: Projection LNG supply and demand. Source: [22]

4.2.2 Natural gas prices

Natural gas prices are made up of several components, such as the wholesale price and taxes and levies.

Price mechanisms

The International Gas Union (IGU) has defined several pricing mechanisms that influence the natural gas wholesale prices [17]. For the countries this report focusses on, the Oil Price Escalation (OPE), Gas-On-Gas-Competition (GOG) and Bilateral Monopoly (BIM) are the most relevant ones.

For each of these mechanisms a short description is given; OPE: linked to a base price and also linked to competing fuels such as crude oil, coal prices or electricity prices. GOG: Supply and demand determines the price, trading occurs on different timespans (daily, monthly etc.) and is traded at notional or physical hubs. BIM: In contrast to GOG, only one large buyer and one large seller are involved who negotiate to determine the price, prices are mostly set for a fixed time-span. Wholesale prices tend to be higher when largely linked to OPE.

Compared to the rest of the world, the Northwest of Europe (France, Germany, United Kingdom, the Netherlands) has seen a large change in the dominating price mechanism influencing the wholesale prices. As indicated by Figure 14, OPE has declined from over 70% in 2005 down to just under 10% in 2016. This is mainly caused by more spot gas imports and more volume traded at hubs. Furthermore, contract renegotiations have led to hybrid pricing, this results in a smaller impact of the oil price on the wholesale natural gas price. Increasing pipeline and LNG imports both have contributed towards GOG pricing, necessary because of declining domestic production.

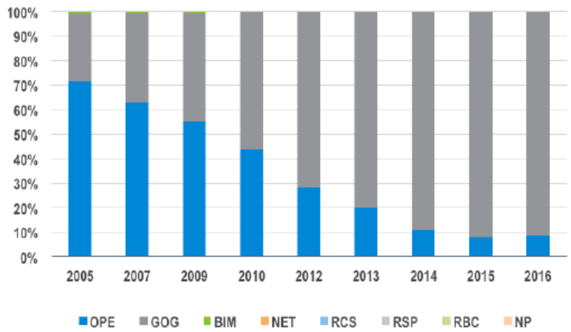

Figure 14 - Northwest Europe price formation 2005 to 2016. Source: [20]

In contrast to the Northwest Europe region, countries such as Italy (Mediterranean region) experience a much smaller change in the pricing mechanisms, OPE dropped from 100% to 68% in 2016.

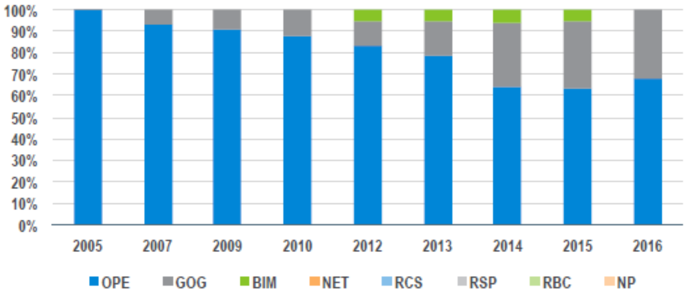

Figure 15 - Mediterranean Price Formation 2005 to 2016. Source: [20]

Wholesale natural gas prices

In Figure 16, historical global natural gas prices are shown [20]. It is clear to see that the prices are volatile throughout most of the period considered and have been much higher for the Asian region compared to the U.S. and Europe. However, one can also see that prices seem to converge from January 2015 onwards.

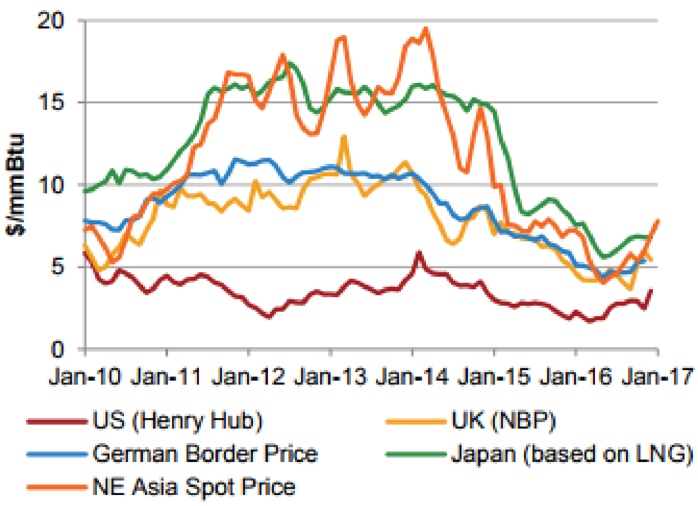

Figure 16 - Monthly average regional gas prices, 2010 - January 2017. Source: [20]

Zooming in on the EU, the average gas import price has fallen by 27% between 2013 and 2015 due to lower oil prices and cheaper LNG as the shale gas revolution in the U.S. continues to expand. The declining LNG import prices for the EU can be seen in Figure 17.

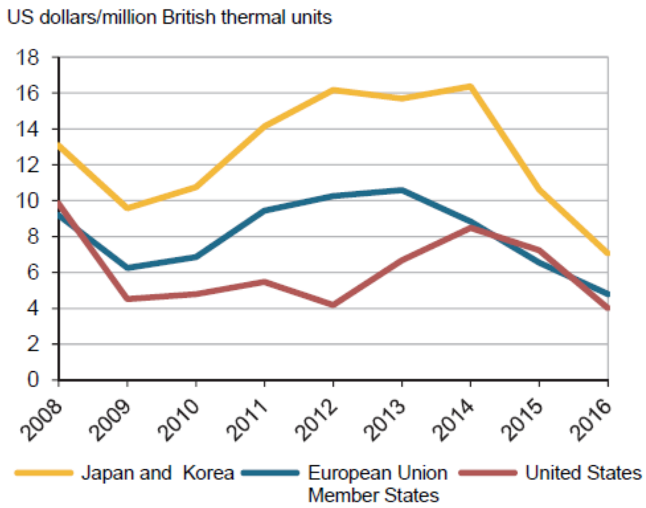

Figure 17 - LNG import prices. Source: [15]

Furthermore, prices are dropping as competitiveness of the European gas market increases. The European commission (EC) projects that on the short term, gas import prices will remain at a low level. On the 2020 horizon the EC expects that prices will remain below peak prices of 2014 and might stay at a comparable level as in 2016 and 2017 [23]. Natural gas wholesale prices from 2020 onwards are further elaborated in paragraph 7.1.4.

4.3 Biogas

Biogas is a relative small source of energy when compared to the total energy consumption in the EU but in terms of market numbers and projected growth it is an interesting market for the C50. In Figure 18 the market development is depicted:

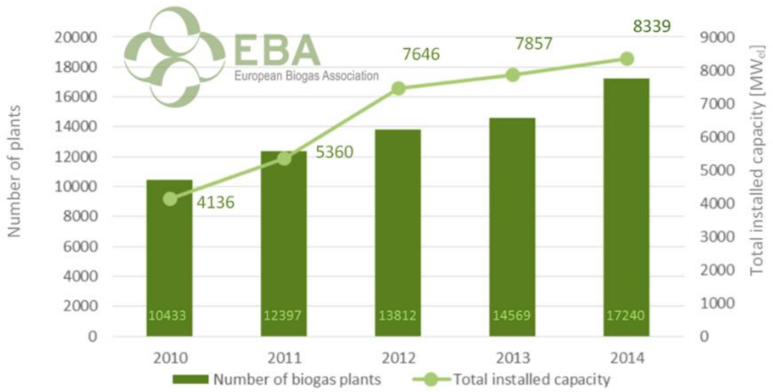

Figure 18: Development of biogas plants 2010-2014. Source: [24]

The predominant sources of biogas are organic waste treatment plants such as sewage, manure and organic waste. In recent years also energy crops have become an important source of energy for this sector, see Figure 19.

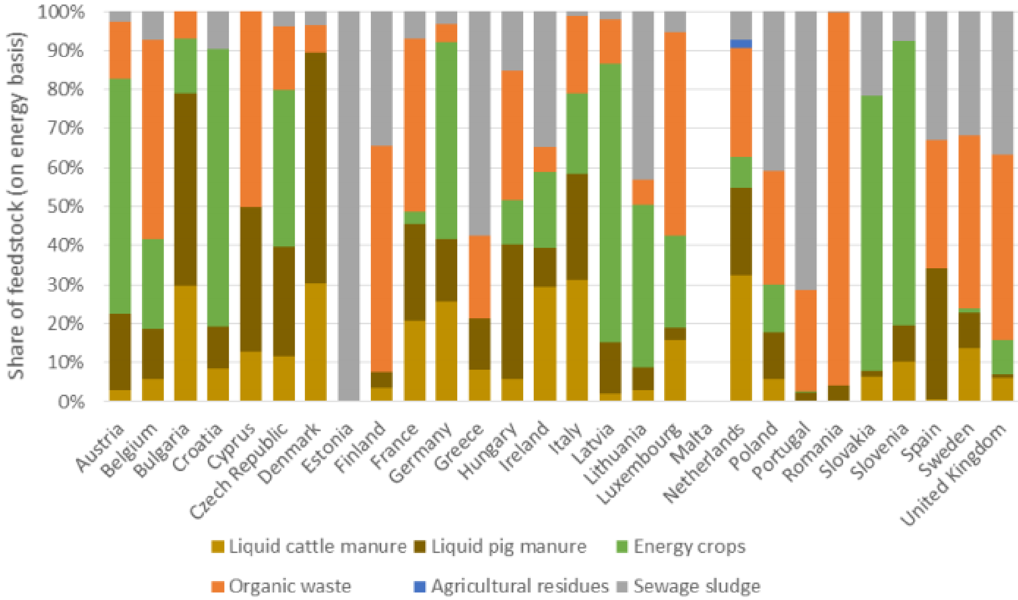

Figure 19: Share of feedstock use for biogas (on energy basis). Source: [25]

The reasons for the historic growth in this sector are two-fold: on the hand, there is a change from current aerobic systems to anaerobic. On the other hand, there is a multitude of incentives such as feed-in programs to support the deployment of biogas digesters. A survey in this sector showed that the existence, stability and reliability of the legal and political framework and effective support scheme(s) is perceived as the greatest driver for the use and consumption of biogas and biomethane.

Germany is a good example of this practice, with its long standing German Renewable Energy Act. This is clearly visible in the installed capacity in Germany (see Figure 20).

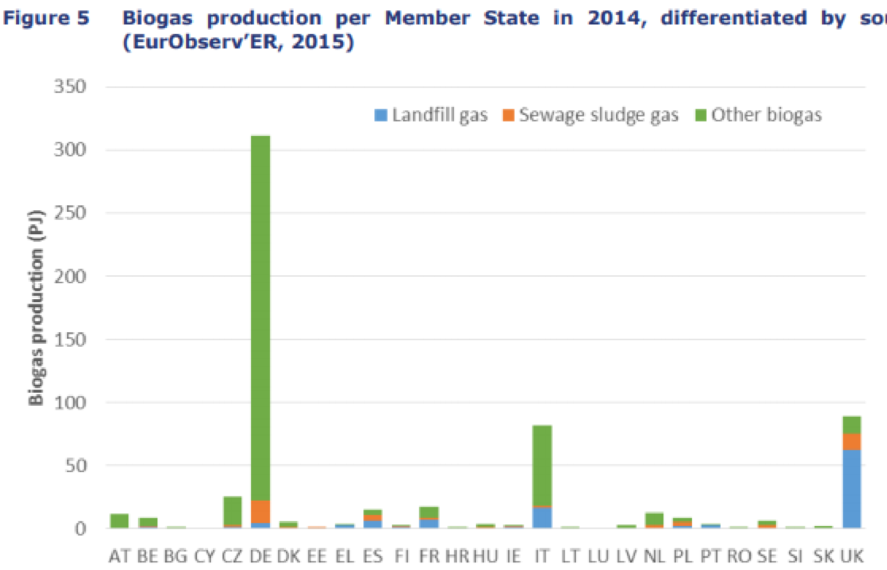

Figure 20: Biogas production in EU. Source: [25]

Prospects

The comprehensive study Biogas beyond 2020 shows the available potential of feedstocks for biogas production in different European Member states. For energy crops this potential has been set to zero, due to political discussions concerning this feedstock. Large growth is expected for feedstocks such as manure and organic waste. Combining the feedstock potential to a technological learning curve and extrapolation of support schemes they estimate that the biogas production will grow with a factor 2 to 3 until 2030. They also indicate how this potential is built up per member state.

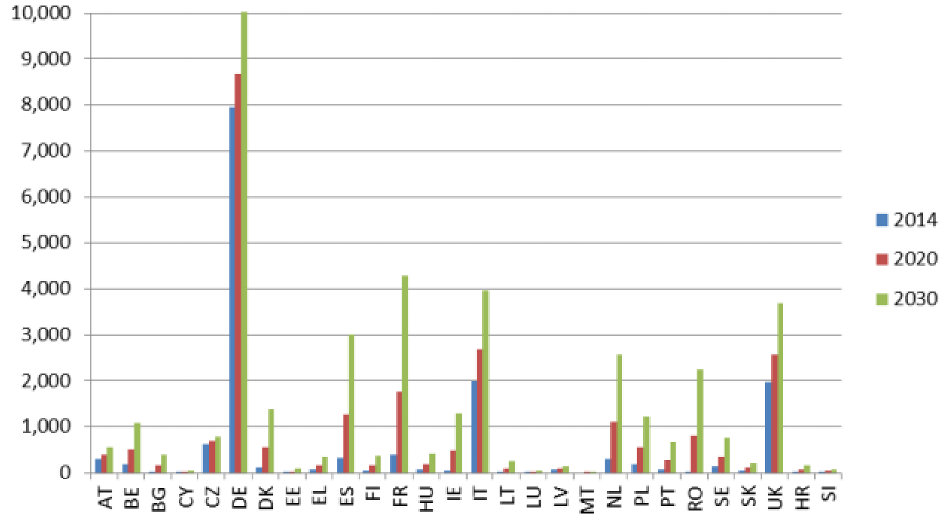

Figure 21: Growth of biogas production per Member State in scenarios 2 and 4 (accelerated growth) in ktoe. Source: [25]

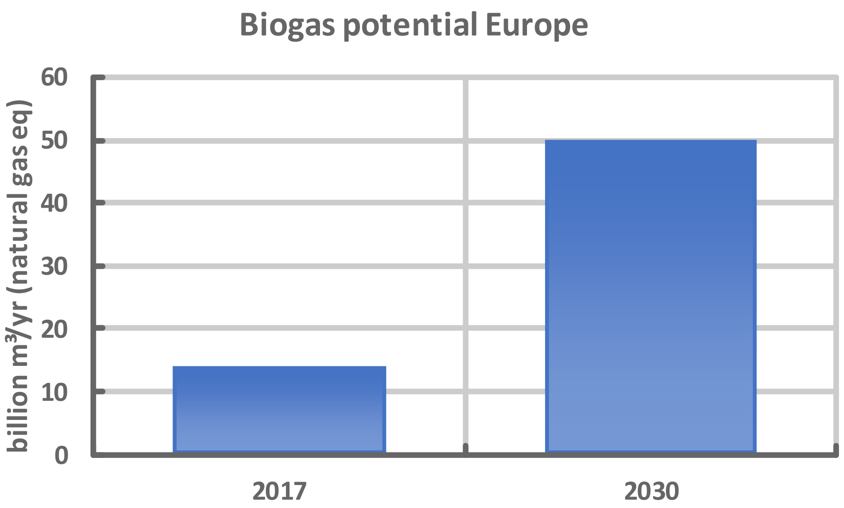

Figure 22: Biogas potential Europe in 2030. Source: [26]

This might be conservative, because new technologies are emerging that can boost production. Current state-of-the-art projects include the application of thermal hydrolysis of sewage sludge, which boosts biogas production by 20% percent. Also, successful tests have been carried out with super critical water gasification which allow for a 40-50% increase of biogas production [27].

Furthermore, biogas production can be combined with hydrogen production. Biogas typically constitutes of 60% methane and 40% CO_2. The latter can be infused with hydrogen (H_2) to form to biomethane. This is done for example in de Audi E-gas project, where 6 MW of electricity is converted into methane.

Biogas production might therefore be a factor 4-5 bigger in 2030 compared to current levels. According to the European Biogas Association, the biogas and biomethane production in Europe will rise from 14 billion m³ today to 50 billion m³ in 2030, covering 10% of current natural gas consumption [26]. Its development creates good and stable opportunities for fuel cell deployment.

Using fuel cell CHP for this biogas production either directly onsite or through a biogas network someplace nearby where heat can be used optimally creates a renewable power production that is 8-10 bigger than current levels, which can act as a flexible source next to intermittent renewables.

4.3.1 Green gas certificates

The role of renewables in the electricity sector is currently well understood, less is known about the potential of renewable gases. If biogas cannot be used onsite, it can be upgraded to biomethane by cleaning it and upgrading to impart certain burn characteristics. The biomethane can be feed into the grid although complicated regulations could be an obstacle for grid injection in some member states. The upgraded biogas in natural gas equivalent quality is also referred to as green gas.

Figure 23: green gas chain. Source: [28]

Like with renewable electricity, each kWh of green gas can be labelled electronically with a unique identifier. This identifier contains, for each kWh of gas, information about where, when and how it was produced. When consumers buy green gas, the certificate is their guarantee that the gas is authentic and has not been sold to any-one else.

Green gas has a clear advantage over renewable sources: it is based on existing infrastructure. Green gas can be fed into the gas grid and can be used by anyone who is connected to the gas network. Because green gas has the same properties as natural gas, equipment does not need to be specially adapted. It could play a major part in the heat (and electricity) mix of the future. Green gas has the potential to cover 40% of domestic heat demand in Europe, according to European DSO grouping Ge-ode [29]. If a CHP operator buys certified green gas, then the electricity and heat produced is green as well.

For businesses, unable or unwilling to switch to all-electric or heating grids, green gas can be an excel-lent alternative. Green gas certificates lead to a premium over the wholesale gas price, which is ex-pected to increase in the future. With this prospect, it is likely that the biogas market will indeed grow. There is a need for a EU recognized green gas certificate market. However, green gas trade is currently a national matter: there is no EU wide trading system, and cross-border trade is currently not possible.

The following volumes are traded on Dutch and British markets:

	Netherlands [30]	UK [31]
Production in million m³ green gas (natural gas-equivalent)	100	400
Amount of C50 fuel cells that could run on this gas volume*	750	3000

Table 1: Green gas volumes

** Assuming baseload operation, fuel consumption 667 MWh/yr.*

The price for green gas certificates is a result of one-on-one agreements between producer and a trader, and is not openly available. Estimated prices are approximately 2 €/MWh, and could increase in the future due to increased demand.

4.4 Hydrogen

Hydrogen is a promising energy carrier as a non-carbon fuel. This could be a fuel for the C50 and depending on the purity levels of the hydrogen produced this could also be used in PEM fuel cells or other fuel cells. Natural gas fired fuel cells might be set aside by environmental organizations as not suitable for the energy transition, since it operates on a fossil fuel and still causes carbon emissions. The use of hydrogen as a fuel fits better in the energy transition and is likely to be accepted more easily as a clean energy technology.

However, hydrogen is not readily available as an energy source. It needs to be produced from other energy carriers such as electricity or natural gas, bringing about a penalization in terms of primary energy efficiency. Furthermore, production facilities, storage facilities, dedicated transport lines and dedicated consumers of hydrogen are needed to utilize hydrogen. In other words, to make use of hydrogen on a large scale, a total value chain needs to be developed. The chicken-egg problem needs to be tackled before new projects can take-off.

In recent years there have been many new initiatives to invigorate H_2 value chains, both big and small, which may also lead to new opportunities for fuel cells. There are several important drivers behind this development:

- Zero-emission mobility with fuel cell cars, trains and ships that need to be fueled
- CO_2-emission reduction in existing natural gas grids
- Renewable projects which lead to excessive grid costs, for example offshore wind, could alternatively choose to convert the produced electricity to hydrogen and transport hydrogen to shore.
- Off-grid applications may use hydrogen as a buffer to deal with weather or seasonal variation.
- Hydrogen is a major chemical commodity, used on a large-scale for ammonia production and in energy-intensive industries such as refineries and steel manufacturing.

Japan is focusing on the transition towards a hydrogen economy and pursues ambitious goals for both mobile and stationary applications. The country's Ministry of Economy, Trade and Industry set a target of 40,000 hydrogen fuel-cell vehicles on its roads by 2020 and 160 fueling stations, up from the 80 hydrogen stations operating right now. The agency also set an $8,000 price target for household polymer electrolyte fuel cells by 2019 and wants to install millions of household sized fuel cells. Also, the hydrogen infrastructure is starting to take shape. Kawasaki Heavy Industries Ltd. and Iwatani Corp. partnered with Kobe city to build a liquefied hydrogen import hub. The project, due to commence operation in 2020, will import hydrogen made from lignite coal in Australia.

Hydrogen mobility is seen a key alternative to electric vehicles, especially in public transportation and heavy duty transport. Many European countries have implemented test programs to determine how hydrogen transportation can be implemented. This has resulted in a diverse range of conclusions. Large scale deployment hasn't taken place yet, but some countries are taking steps. Denmark is probably furthest ahead with the highest density of hydrogen stations per inhabitant and the first to offer a nationwide coverage [32]. Germany has plans to build 400 hydrogen refueling stations in 2023 to align with the number of vehicles. In the beginning of 2017, a total of 106 refueling stations were operating in Europe [33].

The number of electrolysis projects is also increasing steadily, especially in Germany (see map below).

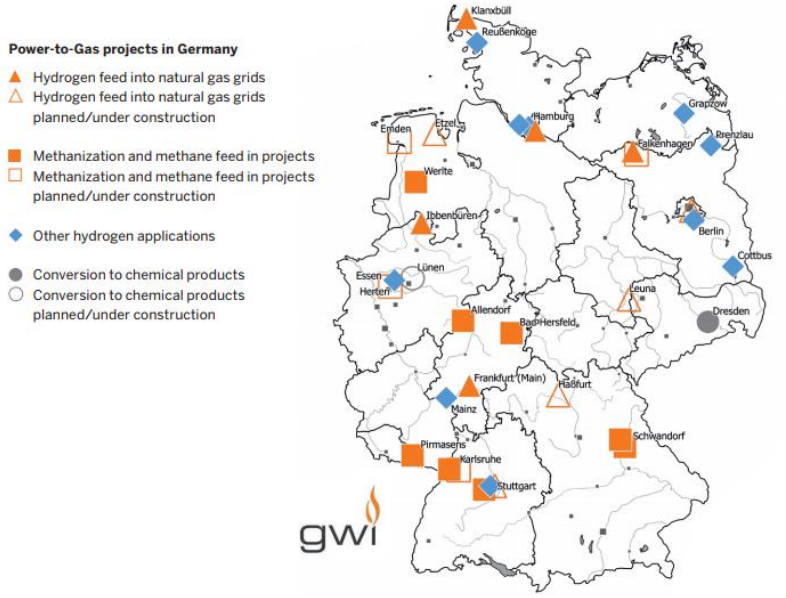

Figure 24: electrolysis and methanation projects in Germany. Source: [34]

These projects mostly feed hydrogen into the existing gas grid. In some cases, the hydrogen is upgraded to methane for use in existing applications.

Finally, some large energy companies are looking into the possibilities for setting up supply chains of hydrogen produced from fossil fuels with the use of Carbon Capture and Storage (CCS). Statoil, Vattenfall and Gasunie have signed a Memorandum of Understanding (MoU) in July 2017 to evaluate the possibilities of converting Vattenfall's gas power plant Magnum in the Netherlands into a hydrogen-powered plant. These supply chains are usually very capital intensive but could be the starting point for a pan-European distribution network for hydrogen. Existing gas grids, with proper adjustments, could be re-used for this purpose.

Figure 25 - Picture of Magnum electricity station, Vattenfall

In Leeds, UK, the H21 project has started to investigate the possibilities to change the complete existing gas grid to hydrogen to get all the carbon emissions out of the city. Leeds is a relatively big city with around 450.000 residents and they have identified technical and organizational pathways to make this transition happen.

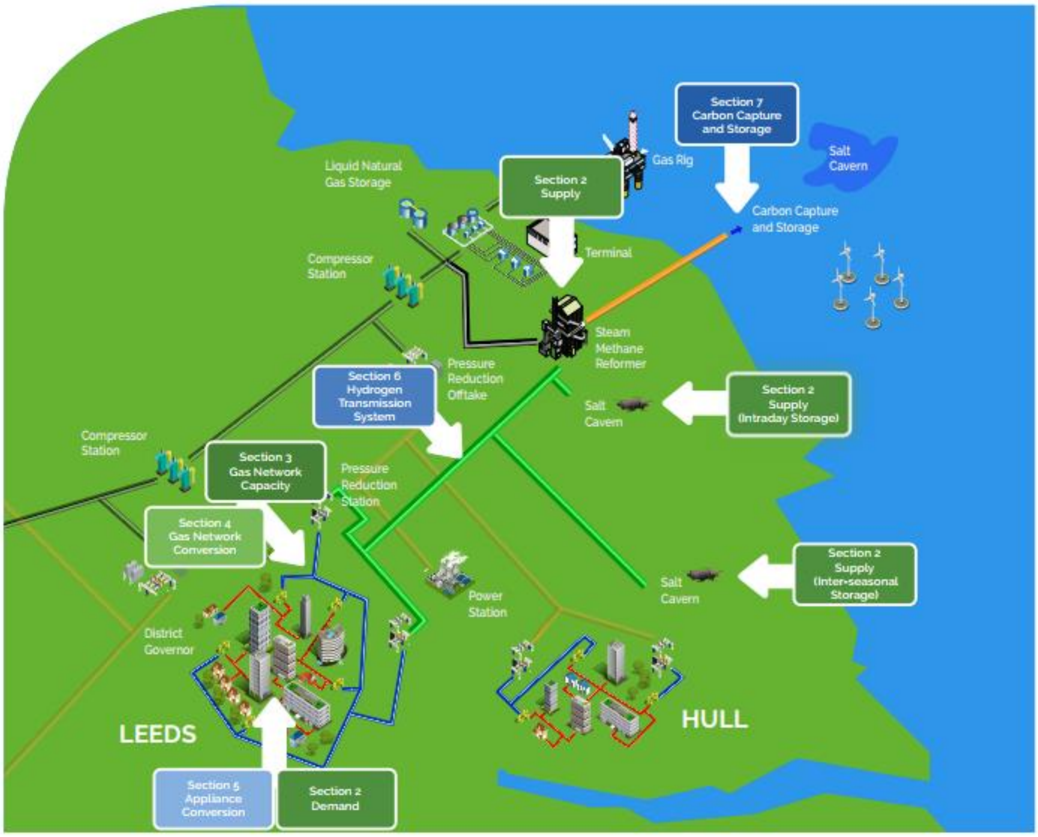

Figure 26: Project proposal H21 in Leeds. Source: [35]

All-in all hydrogen could be an interesting energy carrier for local fuel cell projects in the medium term as it could provide the fuel cell with all the necessary energy and the credibility of a fully carbon neutral source of heat and electricity.

4.5 Conclusions fuel markets

For the future implementation of the C50 we see the following relevant issues for fuel:

- Domestic natural gas production is declining in most countries within Europe. This results in more natural gas that needs to be imported through pipelines or LNG, which will put pressure on the natural gas prices. An increasing demand for electricity combined with a possible coal and/or nuclear phase-out can push prices as well. It is therefore expected that natural gas prices will increase from 2020 onwards.
- Biogas markets will grow substantially (by a factor 4 to 5) up until 2030 and will present interesting opportunities, especially in countries with high feed-in tariffs.
- Hydrogen and synthetic natural gas is a medium to long-term opportunity, whether it would be fossil based with CCS or from renewable sources with P2G, it is a credible solution for a fully carbon neutral supply chain which is compatible with the existing gas infrastructure. At this moment, more research at different H_2 supply chains is required in order to boost the viability of H_2 within Europe's 2050 low carbon energy system.

5 ELECTRICITY MARKETS

In Figure 27, the share in energy sources used for the production of electricity during 1974 up until 2016 is displayed [36]. In recent years several large changes are observed; the share of coal is declining sharply which is compensated by the use of natural gas. A large uptake of renewables like solar and wind can be seen too.

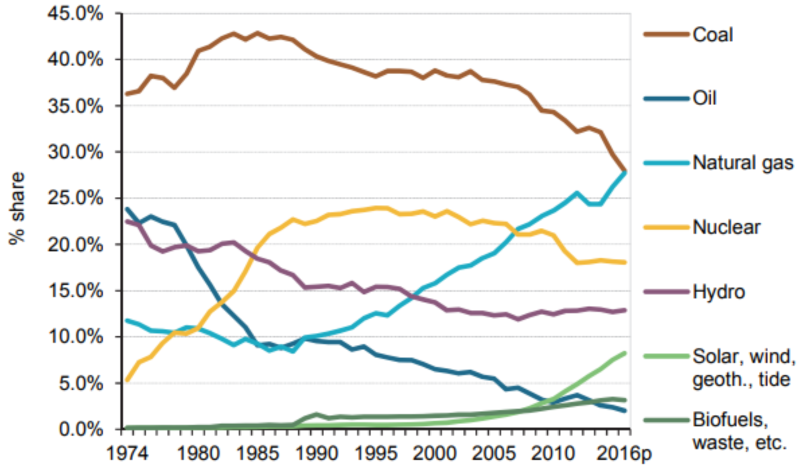

Figure 27 - OECD gross electricity production by source, 1974-2016p, Source: [36]

5.1 Wholesale market

The wholesale market currently consists of three markets:

- Long term *Over the Counter* market. In this futures market volumes are pre-purchased for months, quarters and years in the future
- Day ahead market. On the day-to-day market, supply and demand volumes are offered on an hourly basis.
- Intra-day market. Supply and demand volumes are offered on an hourly basis traded within the day of supply

Currently, electricity producers sell most of their production in advance on forward markets (OTC), committing to deliver a certain amount at a certain time for a certain price. But, demand and production both vary; they don't perfectly match earlier predictions. Such imbalances are then smoothed out by selling and buying electricity on the short-term, or spot market. This is mainly the day ahead market, but trade on intra-day markets is increasing. The electricity price on the OTC market is relatively stable.

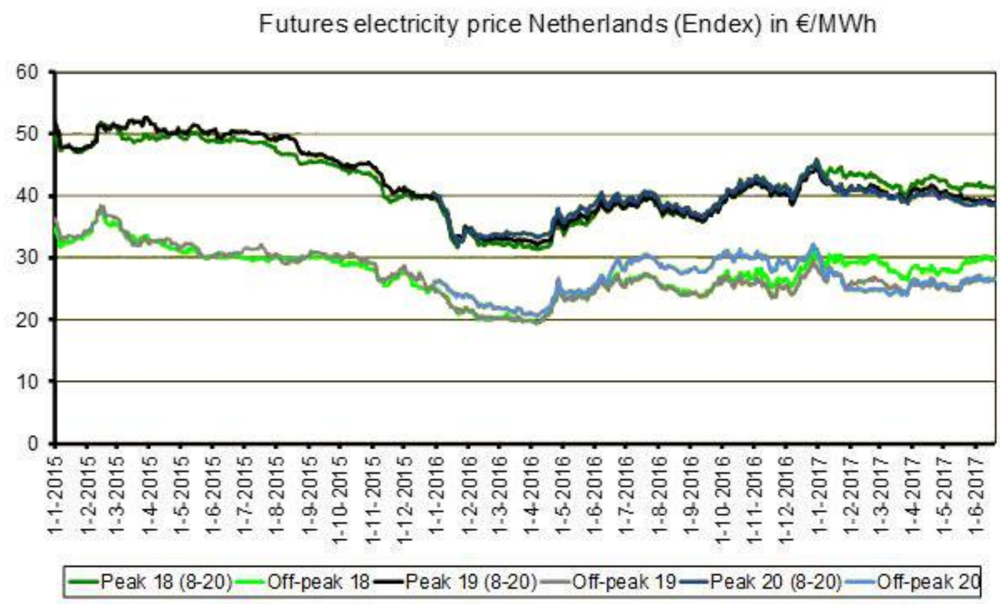

Figure 28: Futures of the Dutch electricity market in €/MWh. Source: [37]

The day-ahead market is much more volatile: prices can vary greatly on an hourly basis. At night, prices are generally low and stable. During day, prices increase with occasional peaks.

There is synchronicity in electricity spot market prices between European countries (see Figure 29). Due to market harmonization and increased interconnectivity, it is expected that prices will further converge in the future.

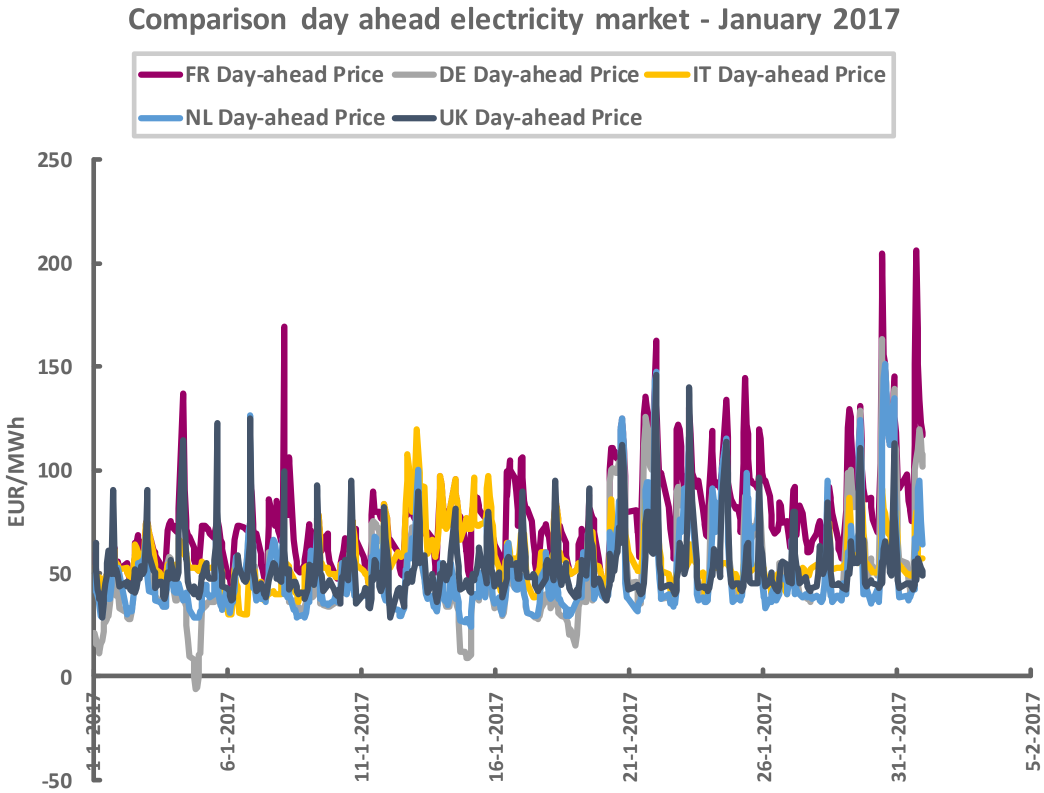

Figure 29: Day ahead spot market prices in January 2017 in Europe. Source: [38].

To assess future market prices, fundamental influences on prices need to be considered. There are major trends in the EU electricity markets:

- The ongoing implementation of intermittent renewable capacity
  - Leading to lower marginal prices in general and higher prices during certain times
  - No more baseload operation and frequent start-stops
  - More flexible reserve power at higher costs
  - Reducing willingness to invest in new capacity due to market uncertainty
- The integration of the European electricity market, both physically and economically.
  - Leading to price converging & and capacity sharing
  - Leading to (near) real time trade
- Electrification of heating, transport and industry
- Phase-out of coal and nuclear capacity
- Developments in energy storage

5.1.1 Intermittent renewables

The energy market is changing rapidly. Renewable energy supply becomes available. Most of the renewable electricity will be variable (VRE), i.e. non-dispatchable due to its fluctuating nature, like wind power and solar power energy. As a result, price differentials will increase within days, hours and minutes.

The current market system is based on the merit order model. This is stated as “a way of ranking available sources of energy, especially electrical generation, based on ascending order of price (which may reflect the order of their short-run marginal costs of production) together with amount of energy that will be generated.” The cheapest production units come first. The production unit where supply meets demand sets the settlement price for all production units. Because VRE has near zero marginal cost, the merit order changes.

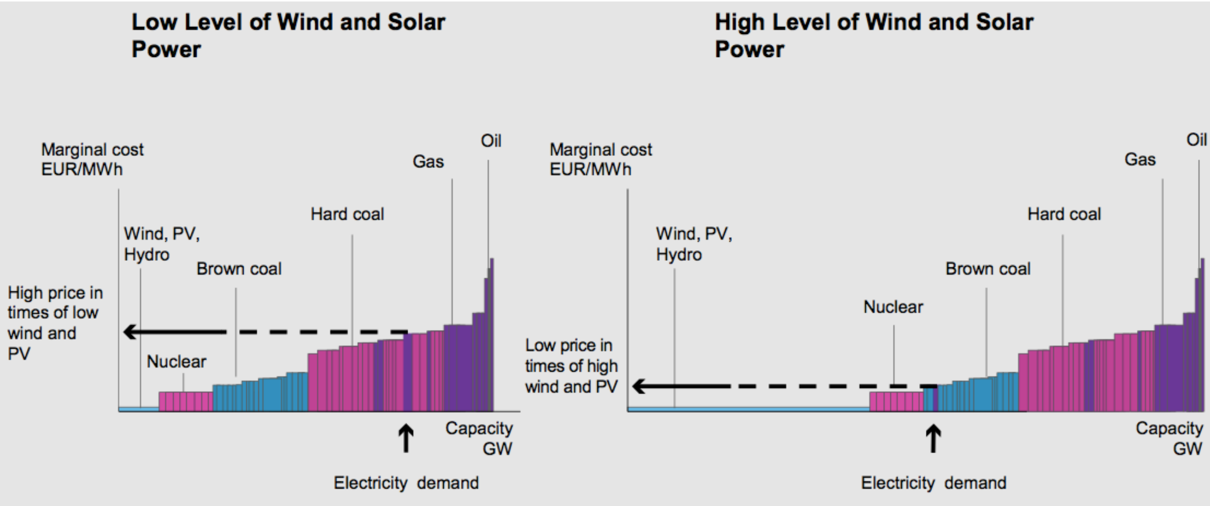

Figure 30: the merit order model. Source: [39]

To give insight on the spread of electricity prices during a year, a duration curve can be created from the settlement prices. This is a sorted curve of hourly electricity prices for a given year. Figure 31 shows the duration curves of Germany and the Netherlands. Germany has more VRE than the Netherlands and its wholesale prices are on average lower. Also, several hundred hours a year the prices drop below 20 €/MWh.

Figure 31: Duration curve of wholesale prices in Germany and the Netherlands in 2015 and 2016. Source: [40]

Due to VRE, there will be moments with abundant supply and moments with shortage, leading to a change in the angle of the curve. At times of abundant supply, the marginal price will approach zero. Power generation systems other than VRE will not be able to run profitably during these hours, leading to a decrease in so-called ‘baseload generation’. This is illustrated in exacerbated form in Figure 32.

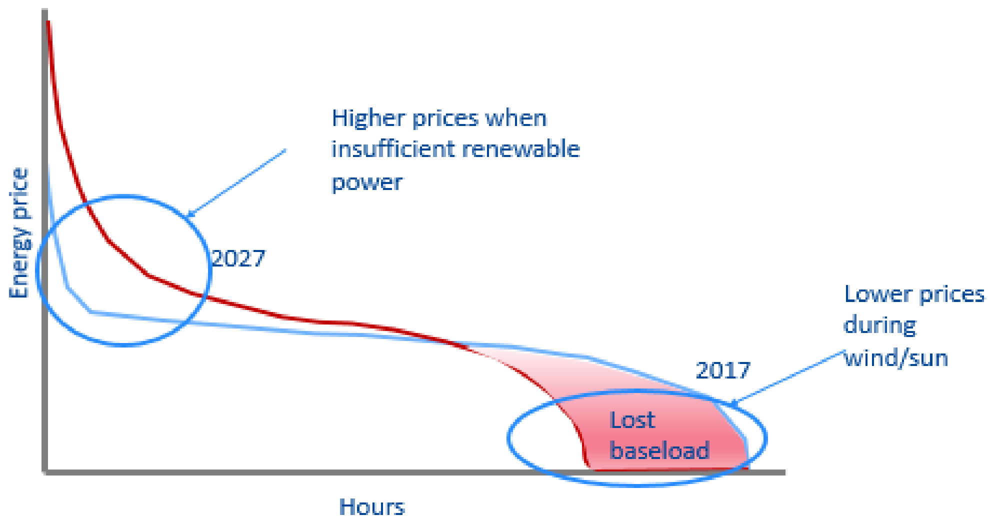

Figure 32: Lost baseload generation due to VRE (fictitious). Source: [41]

It is also expected that during limited VRE the prices will be higher, particularly when coal and nuclear fired plants are taken out of the market and are replaced by the more expensive gas power plants. However, it is uncertain how the market will behave in these hours of lacking VRE production and uncertain how high prices will be. According to leading research by Agora Energiewende, there is plenty of flexibility (although it has no value yet) and securing supply in times of peak load doesn't cost much: a gas turbine can provide the needed capacity at low cost [39].

Flexible generation promises a challenge for fuel cell systems, especially high temperature fuel cells that should be switched off as little as possible. CHP systems that provide power behind the meter are less vulnerable to these changing market conditions because of the leveling effect of taxes and fees and are more suitable for SOFC systems.

An alternative to investing in your own fuel cell is a business model where electricity is bought from the operator at a fixed price, also known as a power purchase agreement (PPA). This gives customers peace of mind with predictable energy costs. These market models are used by fuel cell manufacturers like Bloom Energy and Fuel Cell Energy.

5.1.2 Interconnection of the markets

The EU is currently working on a single European Price Market Coupling which simultaneously determines volumes and prices in all relevant zones, based on the marginal pricing principle. This will lead to increased opportunities for cross-border transmission and to increased price harmonization and stability.

Power trading will gradually move from long term *Over the Counter* contracts to real time pricing. The first steps have already been taken when the price coupling day-ahead markets of North Western Europe went live in 2014.

(Near) real time pricing will become available for an increasing share of consumers. This will be not only for the wholesale markets, but also for flexibility or balancing markets [42].

Interconnection will increase stability of the grid, but there will remain challenges. Due to the weather synchronicity in North-Western Europe, times will occur where there will be a deficit of renewable electricity in the whole region, for example during a low wind winter day. This has been named *Dunkelflaute*. When it happens, it is usually for several consecutive days. These are times when energy storage will not suffice and reliable generation is needed.

5.1.3 Electrification of heating, transport and industry

Electrification within the building, horticultural and industry sector is seen as a promising method for further decarbonization as it is able to replace many natural gas driven applications. In these sectors, the focus lies mainly on heat production by using electrically driven heat pumps and electric furnaces.

Also, within the transportation sector electrification seems to become one of the best solutions for decreasing carbon dioxide emissions, fine particles and NOx. It is expected that electric vehicles will gain a substantial share by 2027 in new light vehicle sales [10]. However, for heavy vehicles the transition towards electrifications will most likely take much longer as range and power are more crucial compared to light vehicles. Nonetheless, electricity demand for the transportation sector will increase significantly in the coming decades.

The combination of electrification in these sectors will increase the electricity demand, potentially leading to higher electricity costs. For example, it is expected that in Holland, extensive electrification of the industry sector could lead to a 40% higher electricity demand [43]. Furthermore, higher loads on the grids are expected too. Due to this effect is it possibly that grid fees will increase too. However, it is expected that this will have no significant impact on the BC.

5.1.4 Phase out coal and nuclear capacity

Coal is currently an important fuel in the European electricity mix, providing over a quarter of electricity generated in 2014. However, in recent years there has been a growing attention for the negative externalities that coal-fired power plants cause with the high level of carbon emissions as main concern. Emission reduction goals such as formulated in the Paris Agreement increase the urge to reduce the use of coal for power production. The role of coal in the European electricity mix is therefore likely to decrease significantly in the coming years.

Several European countries have started to reduce coal-fired generation and already announced their intention to phase out coal fired power plants in the next decades. The United Kingdom has introduced a 'carbon price floor' which resulted in the closing of several coal power plants. Further, it announced that it will close coal-fired power plants in 2025, with restrictions applying from 2023. Since 2010 more than half of all France's coal-fired power stations were shut down and in 2023 coal will be phased out completely. Finland, Denmark, Portugal and Austria are also all aiming to shut down all their coal-fired power plants in the 2020's while Sweden even has announced to phase-out all fossil fuels in the next decade. Others have ambitious goals regarding reduction in CO_2 emissions which would require the closing of their existing coal power fleet. The Dutch government voted for a reduction CO_2 emissions by 55% which would require the closure of their five remaining plants. However, the closure plans are controversial as three of the plants only opened recently. Germany, which relies for more than 40% of their electricity production on coal, moved some of the most carbon-intensive plants to capacity reserve for 4 years, reducing coal capacity with 13%. It has ambitious goals for the reduction of carbon emissions by 2030 which would require a cut of the coal-fired generation by half [44].

Lessons on the consequences of such a phase out can be learned from Ontario, a province in Canada. The provincial government in Ontario decided to eliminate coal-fired electricity in 2003, mainly due to health concerns and air pollution issues. Following this commitment to phase out coal, the proportion of electricity from coal in Ontario fell from approximately 25 per cent of the electricity mix to zero by the end of 2014. During this period coal is substituted in the energy mix by nuclear and renewables, accounting for 60% and 8% of the overall output in 2016, respectively. Despite a doubling of the capacity, adding 5.000 MW, the natural gas output increased only marginally, accounting for 8% of the overall production. The inflation adjusted consumer price of electricity in Ontario has increased since the start of the coal phase-out with 64%. This price increase is partly caused due to the higher unit costs of nuclear power compared to power generation from coal-fired power plants. The stimulation initiatives for renewable energy have had also impact on the consumer price as the cost of subsidies are directly included in this consumer price. Moreover, the investment in new gas capacity which appear to be in excess of typical needs, contribute to higher system wide costs and, hence, higher electricity tariffs [45].

The current electricity market in Europe is different from the one in Ontario 15 years ago both in terms of energy mix as level of market regulation. The levels of nuclear capacity in most countries are way below Ontario's level and are not likely to increase. Several countries have abandoned nuclear or announced to abandon nuclear in the nearby future. France, in which nuclear accounted for 78% in 2014, has the ambition to cut nuclear contribution to 50%. Europe's coal production is therefore not likely to be substituted by nuclear power. The contribution of renewable energy to the electricity production will increase the coming years but due to its intermittent character and lack of large scale storage, it is not a one on one replacement for coal. An increase in the share of gas-fired production in Europe as a consequence of a coal-phase out will therefore be very likely.

The coal phase out will have an increasing effect on the electricity prices since coal has a lower cost per unit of generation than any of its possible substitutions. Especially for countries such as Germany and Poland which rely heavily on coal in their production mix the impact on the electricity supply will be large. The phase out of coal will lead to higher production costs forcing those countries to build new power plants or to cover its demand by imports. For countries as UK and France, less reliant on coal, the impact will be less, although the nuclear reduction goal in France provides an additional challenge.

5.1.5 Energy Storage

Another factor for the consideration of future prices is the share of storage and flexible generation in the market. Those include pump storage units, batteries, possibly electric vehicles, but also flexible loads in terms of demand side management (DSM) from industry and households. The future development of storage and DSM may influence the feasibility of fuel cell business models, because those technologies may smooth the price volatility and limit emergence of very high prices. And if electricity can be stored in large volumes for a prolonged period (weeks rather than days) at high round-trip efficiency this might be very disruptive for both central and decentralised power generation, depending on production potential of renewables.

For example, EWE in Germany is developing a redox-flow battery using underground salt caverns as a storage for the electrolyte. Their intention is to develop a system that can store up to 700 MWh and produce 120 MWe. The electrical capacity of 700 megawatt hours will be enough to supply over 75,000 households with electricity for one day.

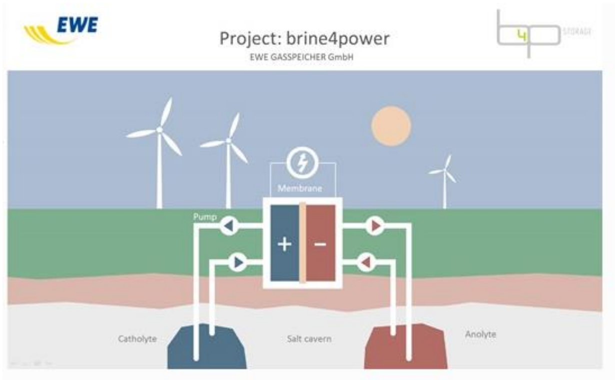

Figure 33: Energy storage project in Germany. Source: [68]

On the other hand, if electrical energy storage becomes much cheaper, this may also allow for new local business model where baseload produced electricity is stored at off-peak and used at peak moments or to create off-grid applications. This is likely to be a realistic transition model as generation capacity that is used to complement renewables will be able to optimize their production. However,
it is not likely that energy storage will fully eliminate the need for backup power nor be able to utilize all excess electricity [46].

At least not by battery storage alone. It is widely considered that when moving to a very high penetration of solar and wind energy, there will be a need for storage in molecules besides storage in electrical, electrochemical or physical form. The reason is that due to low capacity factors, the renewable peak capacity will need to be many times larger than peak demand. A case study for Germany by Agora predicts a peak capacity of 260 GW of wind and solar in 2050, compared to a demand of approximately 100 GW.

5.1.6 Outlook

As was discerned in WP 2.1, the electricity price is the most important business driver. This report therefore has extensively investigated the outlook for the future electricity markets.

Many electricity markets today show downward trends after years of slowly increasing prices. Our assessment is that this is a phase every market will likely to go through, due to (i) low marginal cost of wind and solar and (ii) a fuel shift from gas to coal.

In recent years, central gas power plants have struggled to remain economically attractive. In many European markets, they fail to reach the necessary annual operating hours as they come under merit-order pressure from increasing generation from renewables, more competitive commodity prices for hard coal and lignite and a low price of CO_2 emission certificates on the European Trading Scheme (ETS). Consequently, highly efficient gas-fired power plants have had to shut down in recent years and utilities have tended to shy away from new investments in large conventional power plants with long lead times and payback periods as revenue flows become increasingly unpredictable – at least in the absence of a capacity-based market for permanently available supply.

But coal is likely the first fossil fuel that will be phased out, if the energy transition continues. Combined with rising CO_2- prices and fuel costs and possibly scarcity mark-ups, the electricity prices will start to increase again.

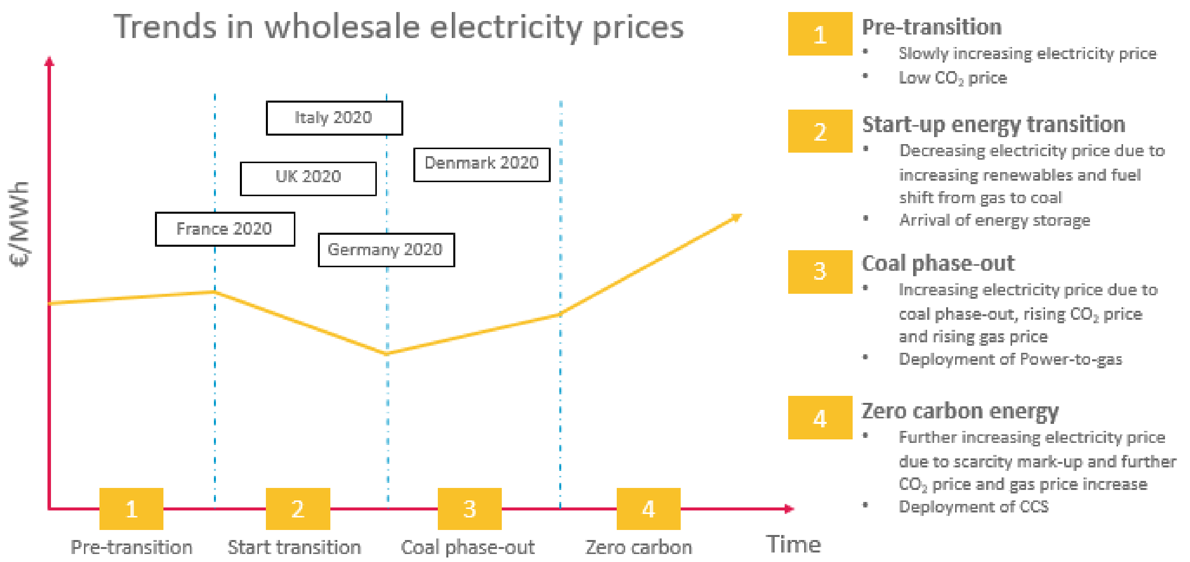

Figure 34: Trends in wholesale electricity prices during the energy transition

Average price levels will increase after coal phase-out. Renewable sources put downward pressure on the prices. But prices must level out to prevent a *tragedy of the commons* scenario[1] leading to capacity stagnation, and due to the increasing importance of combining renewables with a form of storage, renewable electricity cost prices are bound to stabilize or increase.

Carbon capture and storage (CCS) will further increase prices. Extreme prices will also occur more often, but their impact will be limited. Prices will especially peak in wintertime: load shifting and batteries prevent prices from sinking too low in the summer.

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[1] The tragedy of the commons is an economic theory, describing the following. In the absence of regulation, everyone will tend to exploit the commons (in this case renewable energy) to his/her own advantage, typically without limit. In the energy market, the result is not a depletion of renewable energy but rather the depletion of a positive business case for renewable energy because each additional unit of production can lead to lower wholesale prices and lower benefits for all units. This will lead to a stagnation of renewable capacity.

5.2 Balancing markets

The European electricity network is kept in balance by several principles acting on different timescales:

- Primary reserve, or *Frequency Containment Reserve,* is used for balancing within seconds. This means that Frequency Containment Reserve requires a very fast reacting reserve, usually a spinning reserve. Units operating in this market are controlled by the TSO and can provide full power within 30 seconds.
- *Secondary reserve, or Automatic Frequency Restoration Reserve (FRRa),* is used to limit imbalance in the area. Units operating in this market are controlled by the TSO, the price is established through bidding. There is an upward and downward reserve market.
- Tertiary reserve, or *Manual Frequency Restoration Reserve (FRRm),* is similar to FRRa, except that operators are not contracted and only receive the variable fee if they are called upon.
- *Incident Reserve (mFRRda) or Replacement Reserve* (RR) is contracted on a national level and must be able to supply at 100% of the contracted power within 15 minutes. RR is activated if outage continues after deploying FRR.

The sequence of grid balancing is explained below.

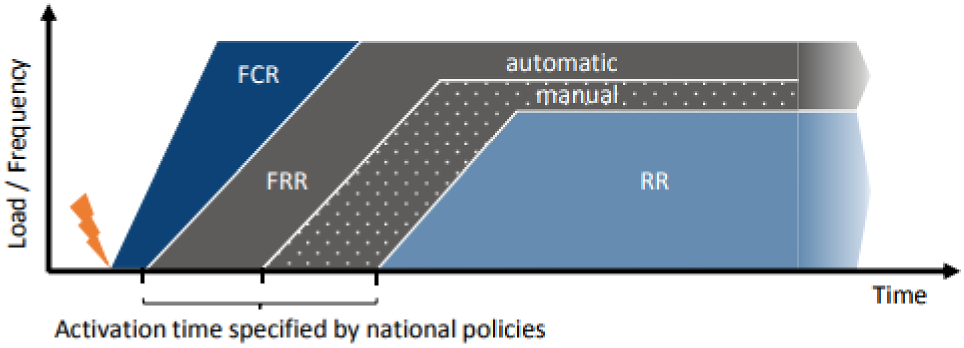

Figure 35: Consecutive activation of control reserve. Source: [47]

Primary reserve

The primary control reserve, or *Frequency Containment Reserve (FCR),* is the system for balancing the frequency (50 Hz) of the energy system in Europe. This controlling power (frequency control) ensures the 50 Hz frequency in Europe. ENTSOE-e (the European Association of network administrators) imposes on countries the ability to contract FCR. The required amount of FCR is determined on a European level. The revenue for FCR is the highest: approximately 2000 €/MW/week (104 €/kW/year). The variability of VRE is greatest at the hourly level and will therefore have little impact on the demand for FCR [48]. Due to market coupling and cross-border balancing, the required FCR market is not expected to grow. The market size is limited, and will likely be dominated by batteries and other forms of fast electricity storage. This market requires very fast reacting units. The FCR market is therefore not suited for SOFCs, both technically and economically.

Secondary and tertiary reserve

Balancing responsible parties (BRPs) are responsible for balancing their perimeter on a 15-minute time interval. BRPs must have a balanced portfolio in day-ahead and have to perform intraday adjustments according to more accurate intraday forecasts and actual measurements of production and consumption. Any residual system imbalance is in last instance resolved by the TSO by deploying a combination of automatic and manual frequency restoration reserves (resp. FRRa and FRRm). There is a tender for up regulation and a tender for down regulation of power.

In contrast to FCR, the required amount of FRR (FRRa and FRRm12) is determined on the national level of the TSO. The growth of VRE will lead to a higher demand in secondary and tertiary reserve. Producers are rewarded with fixed rewards (for FRRa), and if called upon variable rewards. For FRRa, the rewards are approximately 100 €/kW/yr in the Netherlands. The FRRa market is larger than the primary reserve, but is still quite small (400 MW in the Netherlands). The ramp rate required is 7% per minute [49], but profits increase with higher ramp rates. The required ramp rate is considerable for a SOFC system. Operators can operate at part load and sell only part of their systems capacity, enabling room for ramping. However, this means less full-load hours per year.

The tertiary reserve FFRm market is based on a bidding system, where rewards are earned when called upon. There is no fixed fee. In general, the estimated revenue for FFRm will be 10-20 €/kW/year based on the Dutch grid.

Incident reserve and black start facility

Incident reserve and black start reserve are contracted large generators (>60MW and >200MW respectively in the Netherlands) that come into play after FRR when called upon. Due to the nature, size and capital cost of fuel cell systems, they are not suited for these 'back-up power' markets.

In Europe, countries are working towards increasing interconnection and increasing the size of balancing control areas. This has three advantages [41]:

- increasing the size of the control area reduces the impact of any single system event and affords the control area authority a more diverse portfolio of resource options with which to maintain system balance;
- demand across large geographic areas is generally not well correlated and thus the natural variability of demand cancels out to some extent; and
- the variability of variable renewable resources is generally not well correlated over large geographic areas, reducing the variability of supply.

Table 2 displays the current balancing market sizes in several EU countries:

Approximate market size in MW	NL	FR	DE	UK	IT
Baseload demand in MW	10 000	70 000	84 000	35 000	35 000
FCR average market size MW	100	700	600	2 000	Unknown
FRRa average market size MW	400	800	2000	unknown	30
FFRm average market size MW	100	7 500	2000	4 000	Unknown
RR average market size MW	0	12 000	12 000	5 000	Unknown

Table 2: Balancing market sizes in Europe. Source: [50]

These markets are only directly accessible for large generators, so for every market the fuel cell can only participate if added to pooled capacity. Although the market is changing and more demand for flexible power generation will arise, more supply will also find the market including (old) gasturbines, pumped hydro storage from Scandinavia and Alpine countries, electric vehicles and domestic electricity storage. We therefore assume no increase in revenues from balancing markets.

5.3 Capacity markets

As the capacity of intermittent energy production continues to grow rapidly throughout most parts of the EU, polluting coal-fired and nuclear powerplants are phased out, concerns regarding grid stability and energy security rise. The potential problems are caused by the near-zero marginal electricity production costs of renewable power production sources such as wind or solar energy. Due to their low, often subsidized costs, these types of power generation are first in the merit order and push conventional power plants out of the market.

The most expensive generators (peak powerplants) at the end of the merit order are producing less frequently whilst the fixed costs remain stable. This poses a problem for the operators of thermal power plants. In the past, peak power plants could earn extra revenue in the balancing markets. But today there is increased competition from other technologies like battery storage. So marginal costs are under great pressure, and with increasing system cost the market model based on the marginal cost merit order is likely to fail. Who will provide capacity if there is no reward? This problem also counts for VRE sources like wind and solar: new capacity will not be built and existing capacity will not be refinanced in marginal cost based markets.

The changing merit-order is shown in Figure 36. In the new situation, renewable sources indicated by (X) provide a large amount of energy against low costs whereas in the old situation, only a limited amount of energy is generated by renewable sources. At the end of the merit-order the peak generation plants are indicated by Y (in between are sources such as hydro, nuclear and coal plants). These peak generation plants are price-setting.

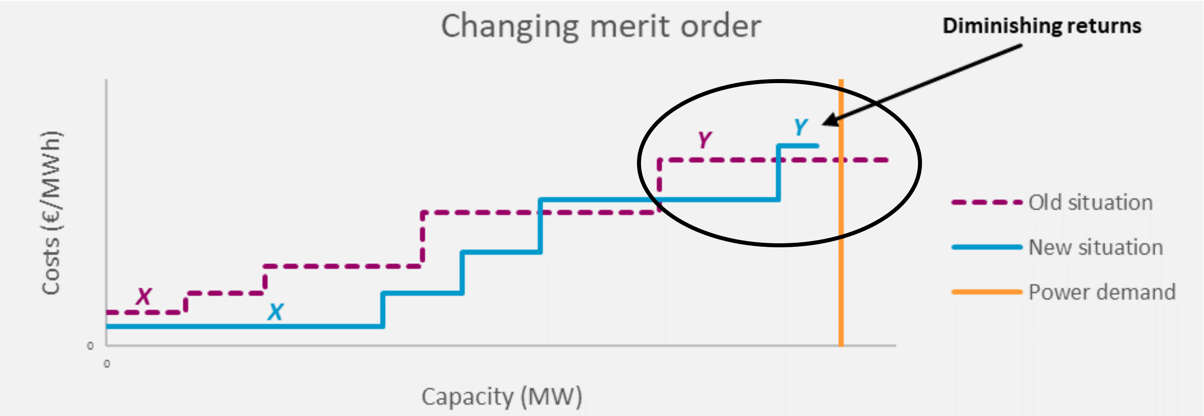

Figure 36 - Indicative merit order model

In the new situation, peak plants have lower operating hours and must switch on and of more frequently than ever before. Due to these diminishing returns, peak generators are becoming less profitable and are being decommissioned or ‘mothballed’ , resulting in stranded assets.

An analysis by Agora Energiewende based on VDE data, indicates that already in 2020, 25% of controllable capacity could be needed for less than 200 hours per year which is not enough to cover costs [39].

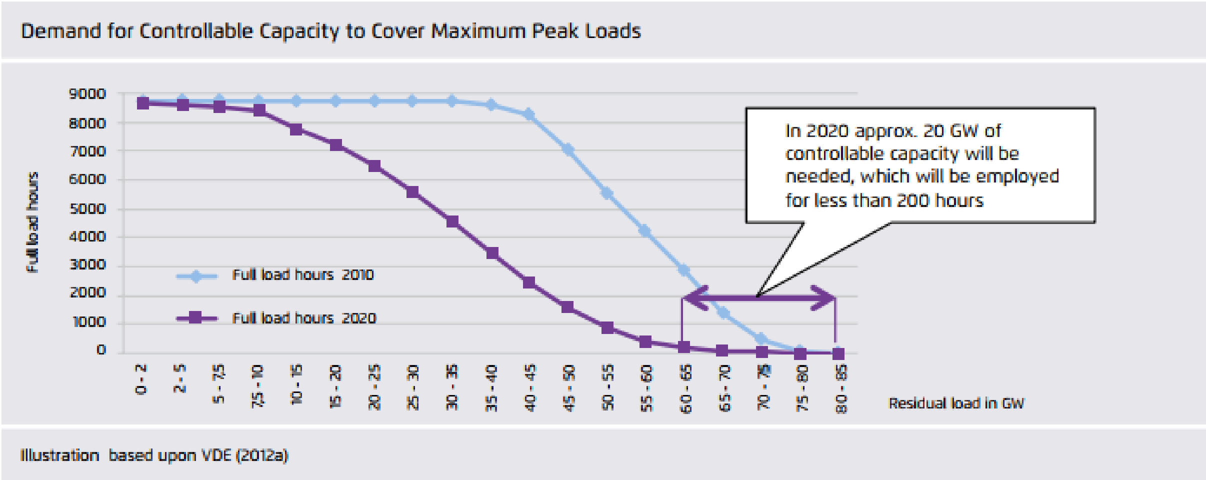

Figure 37: Curve of residual load demand in Germany. Source: [39]

However, when there is little to no wind or sunshine, the amount of electricity generated by renewable sources will be very low as will be the capacity provided by these generators. When this happens to occur on a mid-winter workday afternoon, the demand for power will be high. With ongoing decommissioning of peak generators this might result in a shortage of capacity causing extremely high peak prices and potential disruption to grid services.

In order to prevent these potential problems a (forward) capacity market has been introduced to the power generation market by several countries within the EU. In a capacity market, a remuneration is paid to companies who provide generation capacity. By doing so these companies are compensated for the lack of income caused by the 'energy only' market model (only driven by energy volumes) [51]. As Figure 38 indicates, capacity markets already exist in several EU countries. A capacity remuneration scheme is a difficult matter, and should preferably be an EU wide effort.

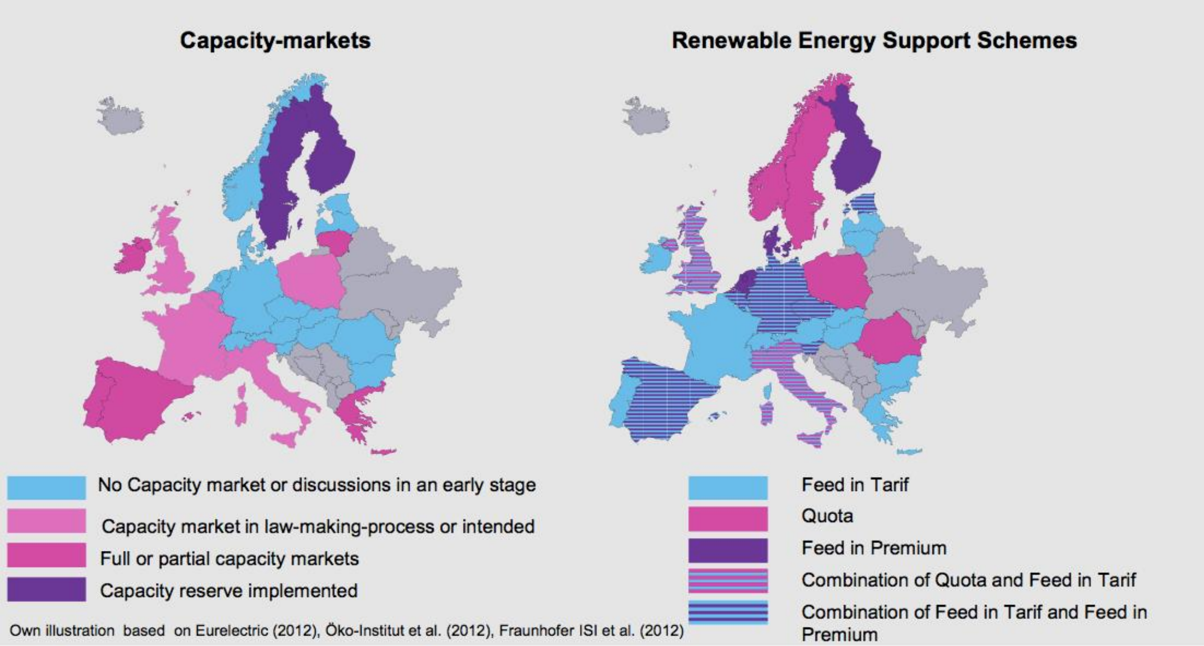

Figure 38: Capacity markets and RES schemes in Europe. Source: [52]

A capacity remuneration scheme is meant to stimulate new capacity or consolidate power plants that would otherwise be decommissioned. A capacity market could potentially serve as an extra value stream for SOFC systems, but the revenues will be small compared to the revenues from (premium) wholesale market.

The value of capacity is limited in today's market. The clearing price in the UK for 2017 was just around 8 €/kW/year [53]. It is estimated by Agora Energiewende that gas turbines can provide capacity for 35-70 €/kW, and that retired power plants could be even cheaper [39]. Very high revenues from capacity market bids therefore seem improbable, also in future markets. Assuming a capacity price of 50€/kW/yr, the annual extra revenue for a 50 kW fuel cell would be 2500 €/yr. This is much lower than other value drivers.

5.4 Value stacking

In the table below an overview is provided regarding the suitability of the application of a SOFC system in a certain market based on the analyses above. It states if the technological characteristics of a SOFC match with the requirements of the market and if the value that can be obtained in the market is positive and how this develops towards 2028.

Market	Technology match SOFC	Market match SOFC	Market suitability - outlook 2028
Self-consumption	Yes	Yes	Positive
Wholesale	Yes	Limited (revenue too low, but increasing)	Positive
Primary reserve FCR	No	No (very limited market size)	Negative

Secondary reserve automatic FRRa	Limited (due to required ramp rate only part of the fuel cell can participate. Inverter might not be suited for direct control by TSO)	Limited (market size small. Some growth expected but the focus will be on FRRm)	Negative
Secondary reserve manual FRRm	Yes (due to required ramp rate only part of the fuel cell can participate)	Limited (growth expected, revenue low, settlement prices unpredictable, high ramp rate needed)	Neutral
Incident reserve / Replacement reserve	Yes (but fuel cell must be already online as a cold start will not meet the time requirements of the TSO)	Limited (this reserve is not called upon often, therefore revenue is low).	Neutral
Capacity market	Yes	Limited (revenue too low)	Neutral

It is possible to combine certain markets and increase the value of the SOFC. There are two logical market combinations:

- Self-consumption/wholesale with tertiary reserve
- Self-consumption/wholesale with capacity markets

For example, you could operate in self consumption mode in part load conditions, and export electricity on the secondary reserve market if prices reach a certain threshold. A capacity market tender also provides value stacking, because energy can be sold as well as capacity. However, in both cases, nearly all value is in the electricity and very little in the balancing reserve or capacity.

5.5 Conclusions electricity market

For the future implementation of the C50 we see the following relevant issues in the electricity market:

- Due to the continuous character of the fuel cell, it suitability is limited to a few markets. The most promising markets are (premium) wholesale, potentially supplemented with secondary reserve (FRRm) and with a capacity market if applicable. These markets will improve slightly until 2028.
- Balancing markets and capacity markets can provide revenue but dwarf in comparison to the value in the wholesale market.
- The electricity wholesale market can only improve in the long to medium term, but timing will vary between countries.
- Countries who start phasing out coal and nuclear power will experience rising prices. These countries can be a good starting market for fuel cells. Countries that are still in an early transition phase

Table 3: Overview of the match between SOFC systems and the described markets

(France, UK) can see prices decrease even further, before they reach a tipping point.

6 ENERGY POLICY

6.1 Set-up and enforcement of energy efficiency policies

It is not likely that organizations and businesses will step on the track to full sustainability all by their own motivation. Strong policy measures are needed as the market for renewable energy is non-existent without current subsidies and taxation measures.

Several policy measures are already in place to increase energy efficiency in Europe. Much more is needed and expected if Member States plan to honor the Paris Climate Agreement. Historically, however, enforcement has been low.

Energy Efficiency Directive

The EED 2012/27/EU is an important directive that aims for reducing energy consumption within the EU. It prescribes that energy consumption should decline with 1,5% per year (excluding the transportation sector). Organizations with a turnover of 50 M€ or more than 250 employees have to perform an energy audit on a 4-year cycle. This audit will push organizations to take energy saving measures that are technically feasible and have a payback time less than five year. While more expensive, a fuel cell might be easier to implement then large-scale renovation.

Energy performance of Buildings Directive

The EPBD is forming the basis for building standards and energy labels. New buildings already have to apply to the *Near Zero Energy Building (NZEB)* standards, which requires high level insulation combined with efficient heating and cooling and solar energy. For existing buildings, there are no general minimum requirements. Member states are exploring options to set minimum energy label targets for existing buildings. The Netherlands has announced that it will enforce a C-rating minimum for all existing office buildings starting in 2023. A similar legislation has become active in parts of the UK too, in both Wales and England it will be unlawful, from April 2018 onwards, to rent residential or commercial buildings if their EPC rating is below ‘E’ [54]. Considering the European wide challenge to reduce CO_2 emissions drastically, it is expected that other countries will likely follow. This can be very beneficial for fuel cells, providing a means to lower energy ratings for buildings. For new buildings, fuel cells with contracted green gas can supplement solar energy to make buildings energy self-sufficient.

Enforcement environmental legislation

Many European countries have environmental legislation in place to assure that industries take measures that have a reasonable pay-back period. This is asserted through regular revisions of Best Available Technologies for example but also takes place within building regulations such as the EPBD. For commercial buildings, SME’s or public buildings there is hardly any legislation that will motivate to take measures. Historically, it has been difficult to describe and enforce any legislation on these issues as it requires a lot of in-depth knowledge and is very time consuming and therefore costly without any revenue. But with good indicators it is possible to enforce environmental legislation. This is done in various ways around the EU:

- Use of existing labelling structure such as product of building energy label
- Look at progress of measures that were identified during an audit
- Create a benchmark within sectors and closely monitor the lagging group

Since this year there are some interesting changes in the enforcement of environmental legislation. In the Netherlands there has been an increase in enforcement of the environmental management act, which requires entities to take measures with a pay-back of five years or less. This is usually coupled to the required energy audits. In other countries the pressure is also rising on companies to take action. Some Member Stated in the EU are thus starting to better enforce current legislation, which drives companies that were previously not interested in these matters to consider their own opportunities and take relevant measures. Moreover, environmental legislation is not only enforced at company or end-user level but when necessary also on a national level. Earlier in 2017, both the Czech Republic and the Netherlands were formally requested to correctly implement and or transpose the EPBD in their national law [55]. With the binding targets coming from the Paris Agreement we expect a further increase in law enforcement and consequently more interest from new customers in energy efficient equipment.

6.2 Energy taxation

National governments impose taxes on fuels and on electricity. These taxes can make up a large part of the energy bill of the consumer. Taxes vary between countries and between energy carriers. Figure 39 shows the average commercial electricity prices in Europe in 2015.

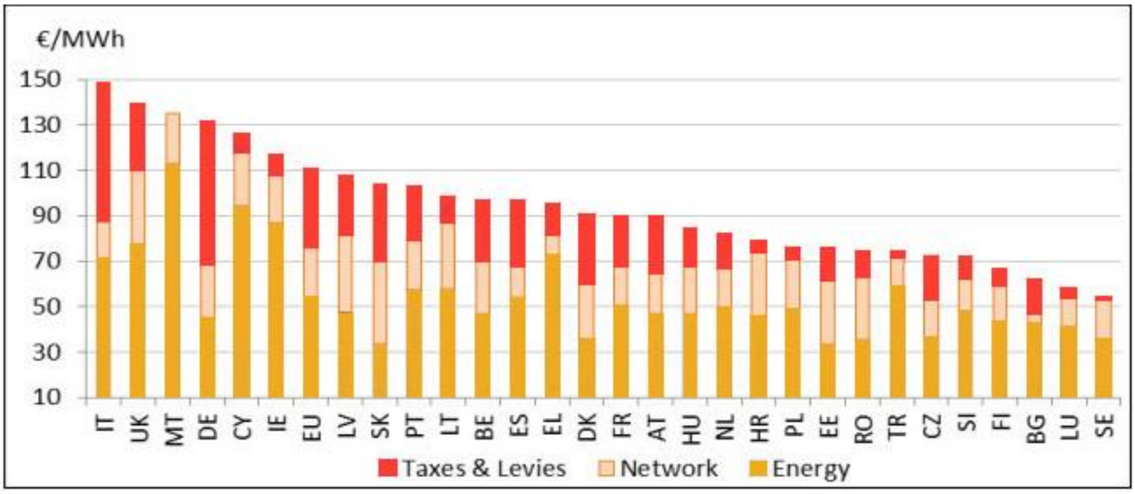

Figure 39: Average commercial retail electricity prices in 2015. Source: [56]

Compared to 2012, in all countries the taxes and levies have increased (see Figure 40) . Fees in Germany and Italy are approximately twice as high in comparison with France, The Netherlands and the UK. Most member states have seen strong growth rates in recent years, up to 15-30% on average per year (see Figure 40). Due to the energy transition, we expect fees to increase steadily, especially for countries with currently low energy taxes. For the analysis, we assume more conservative linear growth rates of 5-8% per year. Due to the time series calculation from 10+ years we use linear growth rates instead of exponential growth rates to prevent unrealistic values in the far future.

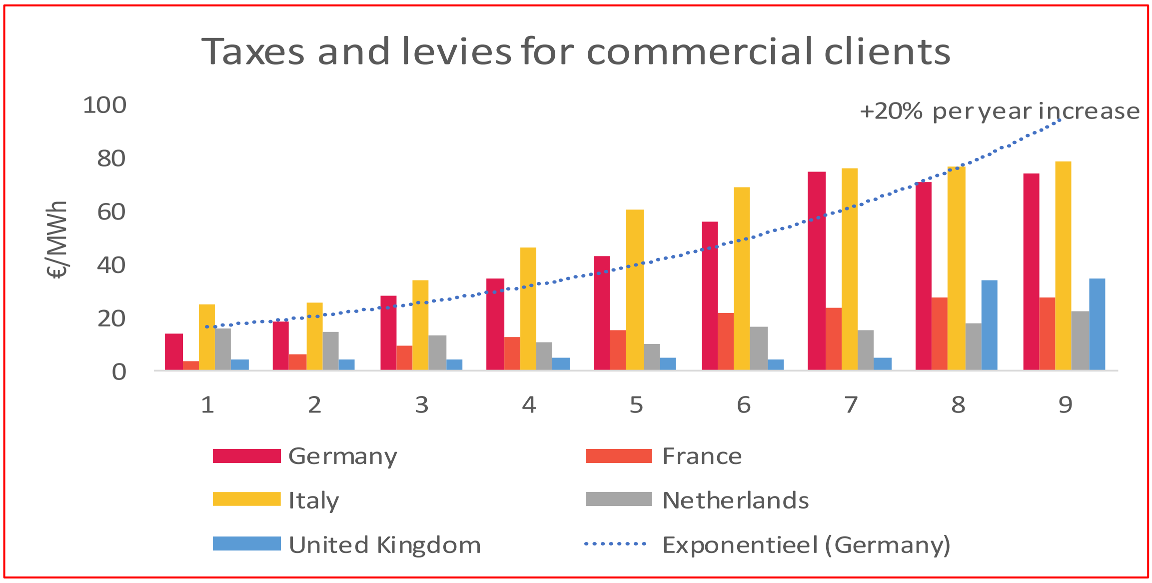

Figure 40: Taxes and levies for commercial clients. Own graph. Data: [57]

Within Europe different taxes and levies are in use on natural gas and electricity. In some countries, for example Germany (EEG-umlage) and the Netherlands (ODE-heffing), there are additional taxes which were put in place to pay for the energy transition. For the sake of simplicity, these levies are included in the energy tax.

In most cases, there is an exemption for fuel tax on natural gas if the gas is used in cogeneration for power and heat. There are two tax related threats to the business case of the fuel cell:

- Removal of tax exemption on (natural) gas, leading to a higher fuel costs (unlikely)
- Tax shift from electricity to natural gas, leading to lower benefits from producing for self-consumption (likely)

Removal of tax exemption

The removal of the tax exemption on natural gas is unlikely, due to the reason of 'double taxation'. When electricity is produced, consumers pay energy tax for the received electricity. If the gas is taxed too, then the electricity is taxed double. (Partial) removal of exemption is unlikely to happen, but this can pose a threat to the business case of the fuel cell. For commercial customers, the tax on gas could be as high as 50%.

Tax shift

There are large differences in taxes between energy types. In Germany, for households, the taxes, levies, fees and surcharges per kilowatt hour are 0.6 cent for heating oil, 2.2 cents for natural gas, 4.7 cents for diesel, 7.3 cents for gasoline and 18.7 cents for electricity. Thus, the extra charges per kilowatt hour of electricity are more than 30 times higher than the taxes levied on heating oil and 8 times higher than natural gas [52]. However, upward pressure on taxes remain as the costs of the energy transition have to be paid. This will be included in energy tax assumptions in the sensitivity analysis in paragraph 7.1.

6.3 Biogas incentives

The market growth of biogas is strongly tied to subsidy schemes. In general, bio-waste can be acquired at low cost, but the equipment needed to produce clean biogas requires a significant investment. Incentives are in place to help finance digesters and gas cleaning equipment. There are four main categories:

- Sewage
- Manure (challenge due to high Sulphur content)
- Land-fill (in most cases not suited for SOFC due to insufficient methane content)
- Organic waste

Subsidy schemes vary per country and over time. A brief outline for selected countries is given below.

Germany

In order to encourage the deployment of renewable energy sources in Germany, the German Renewable Energy Act was revised in 2012 and provides an elaborate subsidy system for electricity generated using biogas. the granted subsidy is guaranteed to be paid for the duration of 20 years and does not vary during the overall payment period. The amount of subsidy which is paid in form of a feed-in tariff is depending on the substrate used for biogas production, the installed electric power capacity as well as the full load hours of the plant. Only electricity is subsidized. The incentives are listed below:

	Base Incentive [eur/MWh_el]
Sewage sludge gas (< 500 kW)	66.9
Liquid manure (<75 kW)	245.0
Organic waste (<500 kW)	156.8

Table 4: German biogas incentives

UK

The UK government has introduced time-limited financial incentives to encourage the use of low-carbon renewable energy generation in the form of Feed-in Tariffs (FiT). For electricity from biogas, the following applies:

	Base Incentive [eur/MWh_el]
Biogas (< 250 kW)	101

Table 5: UK's biogas incentives

France

France has a feed-in tariff for biogas produced electricity. According to its country report (IEA bioenergy), focus is on biogas production with grid injection. With the current social-liberal government, support is expected to remain. There does not appear to be differentiation between biogas sources.

	Base Incentive [eur/MWh_el]
Biogas (< 100 kW)	225

Table 6: French biogas incentives

Italy

The Italian subsidy law exhibits certain similarities compared to the German law: the subsidy in the form of a feed-in tariff for electricity generated using biogas is paid for the duration a 20 years. There is a bonus for the heat produced in bio-CHP systems. Source: SOFCOM [58]. While subsidies are high, they are difficult to acquire.

	Base Incentive [eur/MWh_el]	Bonus CHP heat [eur/MWh_th]
Sewage sludge gas (< 1000 kW)	111	0
Liquid manure (<300 kW)	236	10
Organic waste (<300 kW)	180	40

Table 7: Italian biogas incentives

Netherlands

The Netherlands subsidizes renewable energy with a production premium (premium tariff on top of the sales price) called the SDE+. The subsidy applicants are ranked from the least amount of subsidy required per unit of energy to the most subsidy. Due to achieved cost-down targets for certain technologies, a maximum subsidy of 130 €/MWh for all technologies has been but in place. Heat is also equally subsidized, but in general most heat is used for the digestion. The subsidy cap makes profitable operation hard in the Netherlands, and due to the ranking process, obtaining a subsidy can be hard.

	Base Incentive [eur/MWh_el]	Bonus CHP heat [eur/MWh_th]
Sewage (only for digestion hub for multiple WWTP)	48	48
Liquid manure (<400 kW)	130	130
Organic waste	65	65

Table 8: Dutch biogas Incentives

Summarizing

Biogas incentives vary greatly between countries and source. A differentiation can be made between the following sources:

- Sewage/waste water treatment biogas
- Manure digesters
- Organic waste

In some countries, for example UK or France, there is no incentive differentiation for biomass sources. Other countries show strong differentiation. The DEMOSOFC project has demonstrated the use case for waste water treatment plants. If affordable high-level gas cleaning can be sourced, then manure digesters can prove an interesting market. Although subsidies for energy produced from biogas are high, they are also increasingly hard to obtain and subject to changing regulations.

Nonetheless biogas seems like promising starting market for fuel cell systems.

6.4 CO_2-markets

Background

The EU emissions trading system (EU ETS) is an important tool of the EU's policy to combat climate change and in theory the best tool for reducing greenhouse gas emissions cost-effectively. It is the world's first major carbon market and remains the biggest one. The EU ETS works on the 'cap and trade' principle.

A cap is set on the total amount of certain greenhouse gases that can be emitted by installations covered by the system. The cap is reduced over time so that total emissions fall. Within the cap, companies receive or buy emission allowances which they can trade with one another as needed (Source: EU Commission).

Investment in renewable energy and other low-carbon technologies has progressed apace in Europe, without much help from the EU's emissions trading system (ETS), which has been in place since 2005.

The ETS was designed with the assumption that CO_2 price would start at 30 €/ton. However, after a few years of prices around 20 €/ton the price went down, prices now remain around 5 €/ton. Such low carbon prices are not enough for natural gas to be cheaper than coal. The Commission expects prices to increase to around 20 €/ton in 2023 and 30 €/ton in 2030 due to the decreasing cap (see Figure 41). However, others expect that prices will only start to rise somewhat in the mid-20s, as the huge reserve of emission allowances will then run out. A large price uncertainty remains.

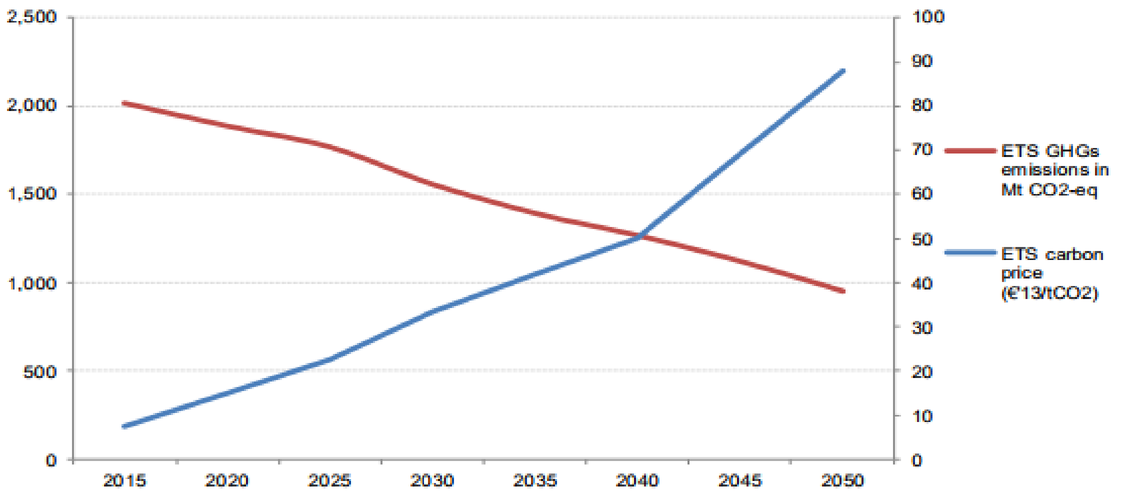

Figure 41: ETS emissions and carbon prices over time. Source: [59]

ETS and Non-ETS sectors

A carbon price is only applicable for ETS sectors, which include power plants and large industry. Currently, other energy consumers are not included in ETS and therefore are not bound by a CO_2 price. Non-ETS sectors have separate reduction goals that are monitored nationally. If a fuel cell owner already falls under ETS, then the power production will fall under the ETS as well (except when biogas is used). If a fuel cell owner is non-ETS, then the carbon price does not apply.

Carbon floor price

By increasing the carbon price, coal becomes more expensive than gas and is pushed out of the electricity mix. The UK introduced a carbon floor price of 9 £/tCO_2-equivalent in 2013, which was increased to 18 £tCO_2-equivalent in 2015. This has been a major factor in driving coal out of the UK electricity mix. Coal output is down two-thirds in 2016 so far, compared to the same period last year. A carbon floor price would be beneficial for energy conversion technologies with a low carbon footprint. Gas will be preferable to coal, but will become less competitive with renewable energy technologies as carbon prices increase. Biogas is considered to be CO_2 neutral, fuel cells operating on biogas will therefore not face a carbon tax.

President Emmanuel Macron from France has reached out to Germany in 2017 to establish a Franco-German (and ultimately EU wide) carbon floor price [60]. The German Renewable Energy Federation (BEE) said a national carbon tax for Germany could serve as an intermediate solution until a common European approach is found, and that a price of 25 €/ton would bring emissions in German's power sector down by one-third by 2020.

Impact on business case

The effect is both direct and indirect. A direct effect could be that the CO_2-savings can be monetized by the operator. When operating baseload and assuming the average EU fuel mix for electricity generation, the fuel cell saves approximately 100 tons of CO_2 per year in natural gas mode, or 300 tons per year in biogas mode. This amounts to 2 or 6 tons of CO_2 per kW. If these CO_2 savings can be monetized, the value is considerable as is shown in Table 9:

	Biogas mode	Natural gas
Low (CO_2 price 15 €/ton)	75 €/kW/yr	30 €/kW/yr
High (CO_2 price 30 €/ton)	150 €/kW/yr	60 €/kW/yr

Table 9: CO_2 reduction benefits

It must be noted the fuel mix varies considerable within the EU, and therefore the benefits will vary greatly as well.

An indirect effect of the CO_2-price is the impact on the wholesale market. If carbon prices go up, these will also drive up the electricity prices. This effect will be described in Paragraph 7.1.1. Care must be taken not to over-estimate the benefit of CO_2 savings.

6.5 Conclusions energy policy

For the future implementation of the C50 we see the following relevant energy policy issues:

- Enforcement of legal requirements on energy efficiency will encourage end-users to invest in measures such as FC CHP. An example can be a new building: a FC CHP can be used to lower primary energy demand and limit the need for solar energy.
- Expected sharp increase on energy tax for electricity for Member states with low taxation levels for businesses. Upward push due to costs of the energy transition. Downward push possible due to tax shift from electricity to fuels, but this will not be enough to stabilize taxes.
- Tax exemption natural gas for power generation available in most countries. Risk for fuel cells is this tax exemption is revoked (will lead to fuel costs +30%), but this is unlikely because it will lead to double taxation.

- Biogas subsidies are available and likely to remain, although not as attractive as in the past as renewable energy sources are starting to compete for subsidies and biogas projects are relatively expensive.
- Increasing CO_2-prices will impact the wholesale electricity market price, but also can provide revenues from CO_2 savings for parties that can use them in the ETS-market.

7 ECONOMIC IMPACT ON USE CASES

In this chapter the economic impact of different parameters are quantified for three different use cases and three scenarios: business as usual, a worst case scenario and best case scenario.

7.1 Parameter projections

7.1.1 Electricity price projection

Based on our observations (see Paragraph 5.1.6), electricity prices are expected to increase strongly. These expectations are in line with research by the Imperial College London with KEMA [61], estimating average prices levels around 80€/MWh in 2030. Price drivers including rising fuel and CO_2 prices, increased demand due to electrification of heat and transport. Price simulations based on the ENTSO-E *Ten-year network development program,* indicate price levels reaching 60 €/MWh, but with notable uncertainty [62].
Even though many signs indicate a price increase is likely, it must be noted, that the market currently shows no indication that prices will rise. At the time of writing, the OTC baseload price for 2021 is still 35 €/MWh.

7.1.2 Electricity tax projections

Energy taxes on electricity have an impact on the value of electricity for self-consumption. Based on the information provided in Chapter 6 there is a trend toward higher taxes and levies. This is not surprising, as system costs are expected to increase due to the energy transition.

The historical tax increase varies greatly within Europe. Where the Netherlands has seen a tax increase for commercial clients of just 3% per year, commercial clients in UK and France have seen their prices go up on average 30% per year. Energy taxes will likely see further increases, especially for countries with a low tax burden for the commercial sector, like The Netherlands, UK and France.

	Energy tax electricity for commercial clients 2017	Energy tax electricity households (premium market) 2017	Tax exemption for CHP
IT	75 €/MWh	75 €/MWh	unknown
DE	80 €/MWh	170 €/MWh	Yes
FR	25 €/MWh	65 €/MWh	Yes
NL	20 €/MWh	120 €/MWh	Yes (minimum system size 60 kW)
UK	35 €/MWh	40 €/MWh	Yes

Table 10: Comparison of energy tax on electricity and applicable exemptions for selected EU countries. Source: [57]

Because values change across countries, we assume average starting value of 50€/MWh for commercial clients and linear growth rates of 5-8% per year. These inputs are used for the trend analysis in Paragraph 7.2.

7.1.3 Biogas incentive projections

There are multiple developments that will influence biogas incentives in the next decade. The following drivers are of particular importance:

Positive drivers:

- Paris climate agreement driving the need for all renewable sources
- Drive towards circularity: proper use of 'waste' products like manure
- Ability to substitute natural gas, which is beneficial due to existing infrastructure

Negative drivers:

- Highly unpredictable markets
- Disillusionment, unsuccessful projects (i.e. digesters relying on expensive co-products)
- More expensive than wind and solar -> challenge to acquire subsidies

Due to cost-down realizations in wind and solar power, it is assumed that subsidy levels for biogas will be reduced as renewable sources have to compete more and more with each other in tender procedures. In any case, it will likely become harder to obtain high subsidies.

As detailed in Paragraph 6.3, incentives vary greatly between countries, and in some cases between. We assume a starting value of 100 €/MWh in 2018.

7.1.4 Gas price projections

Gas prices are expected to increase post 2020 due to increased reliance on imported gas including LNG and due to decreasing overcapacity (see Paragraph 4.2.2 Natural gas prices).

Figure 42 depicts price expectations for Europe based on several sources including the EU Commission and World Bank, and the price expectation for the Netherlands based on the Dutch Energy Outlook (NEV 2016). Based on these sources, the gas price is expected to increase, from approximately 0.15 eur/m^3 (18 eur/MWh) in 2017 to 0.25 eur/m^3 (28 eur/MWh). However, considerable uncertainty remains as is indicated in the right part of Figure 42. The black line displays the historic natural gas price, the green line shows the gas price projection up to 2035 and the green area shows the uncertainty bandwidth in the price projections.

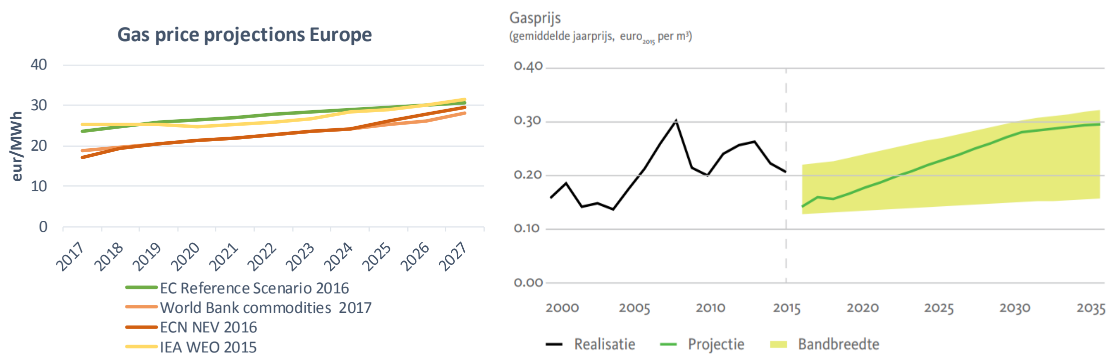

Figure 42: Gas price projection for the EU (left) and for the Netherlands (right). Sources: [63], [23], [13], [64].

Taxes on natural gas are expected to increase strongly. Most countries have a tax exemption for (natural) gas used to produce electricity. If this fuel tax exemption were to be abolished, this can lead to significantly higher gas prices and therefore production costs. This is not likely, due to double taxation standards (see Paragraph 6.3).

7.1.5 Other assumptions

Next to the above described parameters, we assume the following:

Parameters with little /no change expected

- Heat. This is directly coupled with gas price
- Value of grid balancing services
- Value of capacity market payment
- Tax exemption for natural gas and biogas input

Financial

- Discount rate: 5%
- General inflation 2%
- Biogas subsidy remains fixed for 10 years if acquired upon installation.

Technical

- current stack life (32khours)
- Current degradation rates 4%
- Operating hours per year: 8000
- DC power savings: 5% power savings

7.2 Parameters trend analysis

Based on the analysis of the fuel and electricity markets in the previous paragraphs we assume the following parameters for a Business as Usual (BAU), a worst case (WC) and a best case (BC) scenario.

	2018	2023			2028		
	BAU	**WC**	**BAU**	**BC**	**WC**	**BAU**	**BC**
Gas price €/MWh	18	21	18	15	28	23	20
Electricity wholesale	35	42	50	58	50	60	80
Electricity tax €/MWh	50	50	60	70	60	80	100
Biogas subsidies €/MWh	100	50	100	150	50	100	150
CO_2-price	5	5	10	15	10	20	30

Table 11: Today and future - price level assumptions for analysis

With interpolation, four projections have been generated. These parameter projection time series are used in the analysis in Paragraph 7.2.

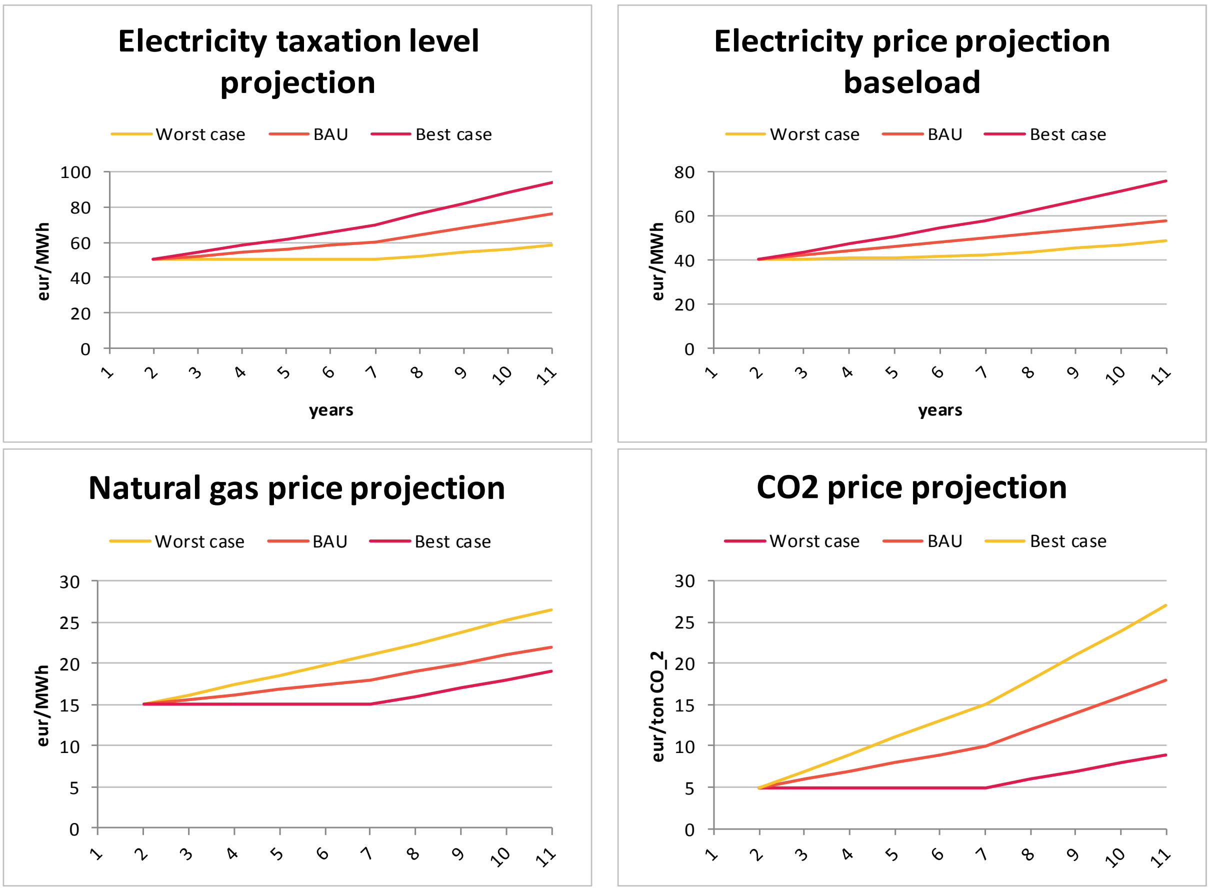

Figure 43: Price projections electricity, tax, gas and CO_2

7.3 Economic impact trend analysis

The economic impact analysis is based on the business analysis of the work carried out under D2.1 for three different use cases:

- Natural gas based CHP (NG case)
- Biogas CHP
- Prime power datacenter application

In order to make the influence of parameters visible we use a discounted cash flow (DCF) model that simulates all cash flows over a period of 10 years. Stack replacements are excluded to make this analysis independent of the positioning on the learning curve. This way, the total investment should cover a ten-year operation including stack replacement when applicable.

Assuming a premium customer that is willing to accept a payback period of ten years (e.g. NPV of 0 over project period), this leads to a net present value which gives an indication of acceptable price levels. Investment costs and stack replacement have to be paid out of this budget. For example, if the acceptable system price is 5000 €/kW, then the total cash available for the initial investment plus necessary stack replacements for a 10-year operation is 5000 €/kW. If the system is cheaper, the net present value is positive. If it is more expensive, the net present value is negative. We repeat this simulation for three systems installed in different points in time:

- Systems installed in 2018 (and operating until 2028)
- Systems installed in 2023 (and operating until 2033)

- Systems installed in 2028 (and operating until 2038)

7.3.1 Conventional CHP

First, we look at a conventional natural gas CHP unit placed at a commercial consumer[2].

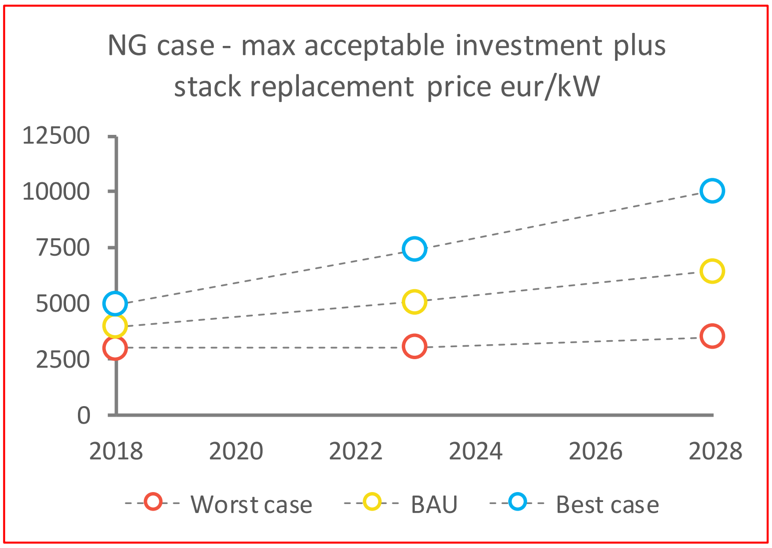

Figure 44: Economic impact natural gas CHP

Under BAU assumptions we see a steady increase in profitability up to 28% in the medium term, with a relative high upward potential in the best case, which is mostly related to the electricity price. Assuming a system with full load hours, the increasing electricity price and energy taxes lead to a much better business case than today. In the worst case, acceptable investment plus stack replacement price levels remain close to their value today, at less than 3000 eur/kW.

[2] This is not a premium market segment as distinguished in D2.1m, such as a collective apartment building. It uses standard energy tax levels (starting at 50 €/MWh in 2018).

7.3.2 Biogas-CHP

In the biogas case, we assume a newly built digester where the biogas subsidy also has to cover the expense of the digester. The benefit of a fuel cell is the additional electricity produced compared to a gas engine. For the biogas-case we only take the additional energy produced through the use of a fuel cell rather than a gas engine in this size range and we deduct the investment cost of the gas engine to the balance.

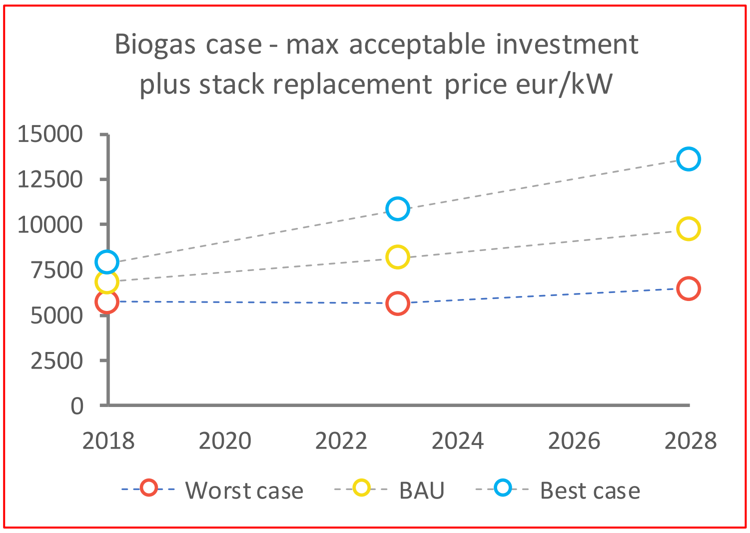

Figure 45: Economic impact biogas CHP

The business case is better in general for the biogas case, with higher annual revenues. The BAU scenario shows a significant improvement of around 19% in 2023 compared to 2018, assuming stabilizing subsidies and increasing electricity and tax levels. A small added benefit exists if the produced or abated CO_2 has a value. The value of electricity (including taxes) remains the dominant value driver.

7.3.3 Prime power data center

For prime power, the following special value drivers are taken into account:

- DC savings: 5% energy savings due to omitted transmission losses
- Savings on back-up power equipment (smaller UPS, generator, switch gear)

The value of system configurations benefits of newly build datacenters are not yet taken into account, although they will be analyzed in more detail in a later stage.

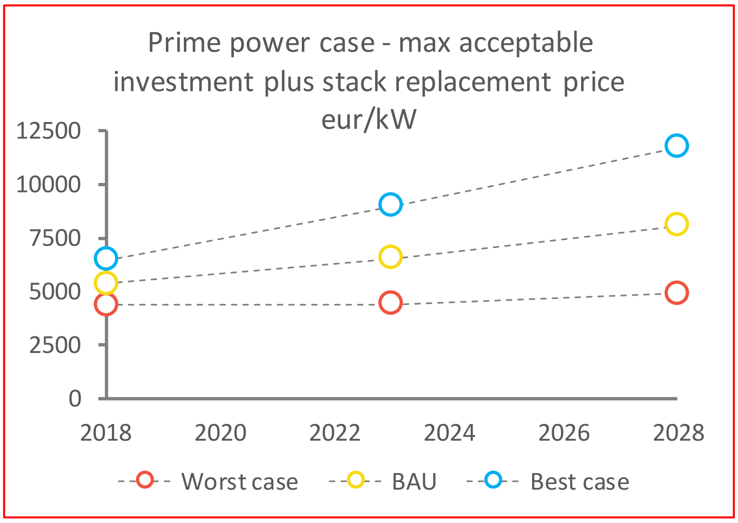

Figure 46:Economic impact prime power

For the BAU case, a similar improvement of more than 20% compared to 2018 can be seen as in the natural gas case, with also the same sensitivity caused by the electricity price and the electricity tax.

7.4 Conclusions trend analysis

The stated trends lead to the following business case improvements compared to 2018:

Improvement to 2018 under BAU	2023	2028
Natural gas case	+28%	+63%
Biogas case	+19%	+42%
Datacenter case	+22%	+50%

Table 12: business case analyses

The uncertainty bandwidth for the important parameters is large. In general, the following trends are expected:

- Strong increase in electricity prices caused by the energy transition, i.e. imminent coal and nuclear phase-out, rising CO_2-prices and general scarcity effects due to increasing demand and decreasing conventional centralized capacity.
- Strong increase in energy taxes to pay for the energy transition
- Increase in gas prices expected due to increasing dependence on gas imports
- Stabilizing subsidies for biogas expected due to decreasing costs of renewables on the one hand but necessary market growth in order to success in the energy transition on the other hand.

8 CONCLUSIONS

The EU energy system is changing at a rapid pace to fulfill the demand for affordable, reliable and more sustainable energy. At the heart of these developments lies a technological revolution for wind, solar and other sources of renewable energy. Together with the digitalization and decentralization this is impacting the complexity, organization and economics of the energy market. Traditional energy companies with a largely centralized generation portfolio are struggling to keep pace with these developments. How does the C50 fit in this new paradigm of decentralized, high efficient and renewable energy sources?

This report identifies the most important developments and quantifies the economic impact that these factors will have on the business cases.

8.1 The only way is up

Regarding the business case for the C50, the electricity price is one of the most sensitive factors. Looking ahead we expect wholesale electricity prices to decline in the short term (depending on MS) and to rise sharply in the medium term. This is summarized in the graph below.

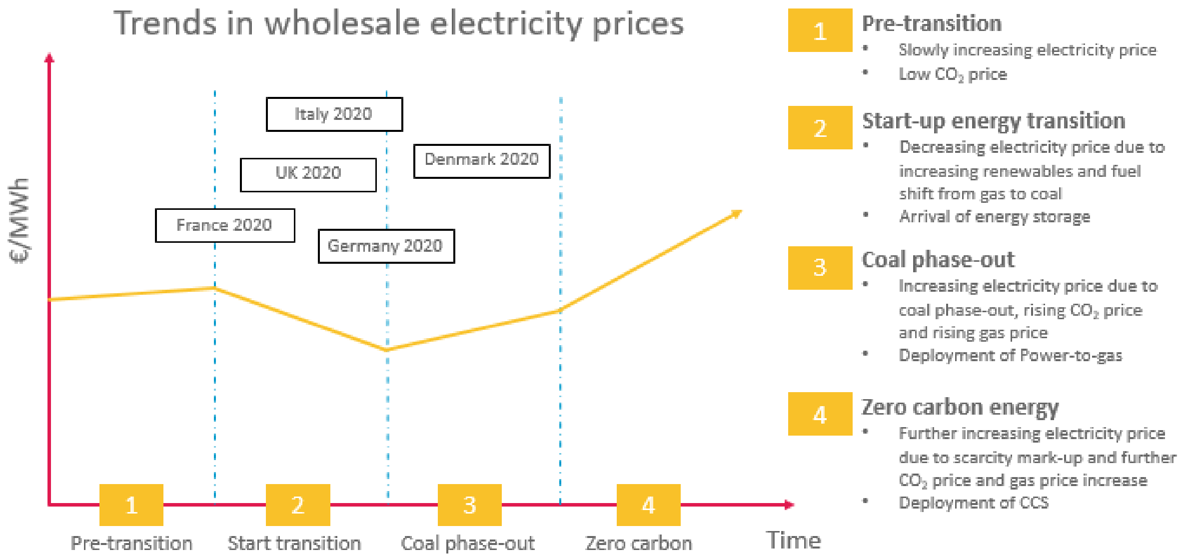

Figure 47: Trends in wholesale electricity prices

In which of the above price phase the different Member states are, depends on the specific characteristic of these Member states: especially their energy policy and current share of renewables. However, the differences between countries are disappearing due to increasing market coupling and price harmonization. For all Member States, the medium to long term outlook is one way: up.

8.2 Trend overview

We have also categorized the most important trends on the short- to medium term that might influence the market development into three categories: policy, market and users. This leads to the following overview:

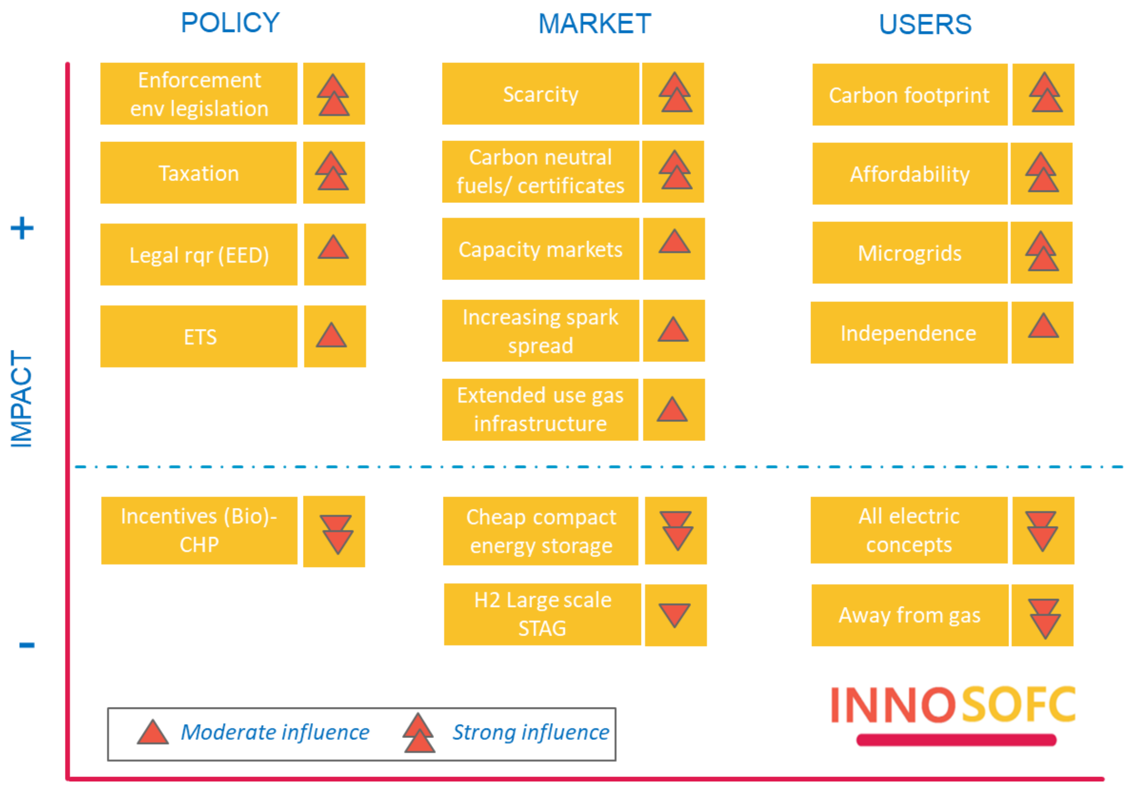

Figure 48: Overview future trends impacting market developments of the C50

The overall picture shows that the C50 can profit from a broad range of future trends on all categories. Existing policies to stimulate energy efficiency and renewable energy production will have a big impact.

On the market side, there is a two-fold effect. On the one hand, we expect an increase from the wholesale prices of electricity in energy markets with a high share of renewable energy. Even though natural gas prices are expected to rise too, the overall spark spread is expected to improve, especially if European Member States move to phase-out coal fired power. If public support for the energy transition remains, this will likely happen soon. The effect is amplified by strong increasing tax regimes. We therefore expect a strong upswing in businesses cases in the medium term, depending on the share of renewable energy in each Member State.

On the other hand, it will become more and more difficult for existing energy companies to invest in new large-scale central power generation. Already most new capacity is variable renewable capacity. This will likely lead to more scarcity on the electricity market and thus a higher mark-up on prices. A second effect could be the establishment of capacity markets as a means for countries to firm their strategic capacity. In both cases this would result in an added revenue for fuel cell CHPs, though the fuel cells would benefit less from a capacity market than from the wholesale market. In addition to this, energy companies may opt to build their own fleet of decentralized generation units as a part of their strategy. At the demand side, we expect that demand for ultra-efficient, emission-free and clean solutions will increase sharply, due to increased willingness to reduce carbon footprint (caused by legal or shareholder requirements) and a demand for affordable and predictable prices. These trends are complemented by increasing pressure on end-users to take action resulting from energy policy i.e. the enforcement of environmental legislation.

The three business propositions natural gas CHP, biogas-CHP and prime power that were analyzed in this report show a favorable outlook, mostly due to the prospects on the electricity market. The production of biogas is likely to grow a factor 4 up to 5, which makes it a very interesting growth market. Prime power applications using fuel cells have yet to be investigated more thoroughly for its benefits at a system level eliminating electrical infrastructure.

The trend analysis shows that there will be improved opportunities for fuel cell CHP. Some threats arise, for example movement to all-electric concepts and other energy concepts that do not require the use of fossil fuels. The C50-proposition needs to address these trends to find its right place in the market. One solution could be to work with green gas certificates, which are readily available in most EU countries. Another way is to address market segments which where the all-electric route leads to high infrastructure costs, or where infrastructure costs can be eliminated due to localized DC power for data centers.

8.3 Recommendations

Given the great differences between the three business propositions in terms of market routes, market diversity and value created by the C50 we propose to focus on the following:

- Renewable applications (biogas) in premium bio-CHP subsidized markets (currently Germany, France and Italy) and customers with a baseload power need who can consume the power onsite.
- Develop a proposition for prime power systems, where the peak capacity is optimally used, possibly with the use a battery pack with high capacity.
- For natural gas CHP, focus on the development of niche markets as determined in WP2.1. At the same time keep track of markets with the right conditions for future growth of electricity prices (Germany) and possibly CHP incentives.
- Develop a proposition for customers that want to use the C50 as a complement to their own renewable energy production e.g. load following systems based on several C50's using a battery pack for peak loads.
- Determine a marketing strategy that is adaptable to the needs in different EU member states that can address the suitability of the C50 for each customer in terms of carbon footprint, competing alternatives, added features such as increased reliability and possibility of transition towards zero-carbon fuel.

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