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Electricity market designs and flexibility

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Summary

Rapid increase of varying renewable-based electricity with low marginal cost is challenging the practices applied in electricity markets. This report focuses on *how the electricity markets can be organised so that flexibility is efficiently tackled*, i.e. *market design*. Thus, instead of technological means, attention is paid to a question on how market system could contribute the flexibility need and supply. According to the report, current advanced electricity market designs offer possibilities for trading flexible resources to some extent. Furthermore, many of the shortcomings identified in current market designs seem to relate to general characteristics of electricity markets. Thus, making explicit conclusions on adequate market design for flexibility is challenging. However, capacity mechanisms, increasing flexible components in market systems and fundamentally novel type of market solutions are discussed as potential directions for addressing flexibility in market design.

Despite often presented solution for shortcomings of current market design during the last few years, according to the report, traditional capacity mechanisms seem to have been designed to tackle the fundamental shortcomings of electricity markets such as lack of price-responsive demand, limitations in storing the product, and vulnerability to market power during times of high demand. Thus, it is seen possible that only relying on traditional capacity mechanisms may not be adequate for tackling the flexibility question. For increasing flexible components in competitive electricity markets, well-known measures include improvements in intraday and real-time markets, more efficient and dynamic prices, higher geographical or temporal resolution, capacity prices, and demand response participation. Whereas all these measures have potential to contribute in addressing flexibility, the highest attention is paid to analysis of novel type of two-market system presented by Keay (2016), which is fundamentally designed to address the flexibility issues in current operational environment. Especially, its applicability in Nordic electricity market is considered.

We present a thought experiment of how a separate intermittent renewable market, basically a wind power market in the Nordic system, could be made to work using mainly the tools and market structures of the Finnish and Nordic market we have already today. The basis for this alternative is to split the markets with a firewall and have a Wind System Operator managing the wind market. The main point is to let all end-users in the wind market purchase the production at a discount, but at the same time directly be balance responsible.

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Preface

This work was carried out in the research program Flexible Energy Systems (FLEXe) and supported by Tekes – the Finnish Funding Agency for Innovation. The aim of FLEXe is to create novel technological and business concepts enhancing the radical transition from the current energy systems towards sustainable systems. FLEXe consortium consists of 17 industrial partners and 10 research organisations. The programme is coordinated by CLIC Innovation Ltd (www.clicinnovation.fi).

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1. Introduction

This report is about considering electricity market design based means of bringing more flexibility in modern energy systems. The considered systems include high share of electricity generated by variable renewable energy sources. Technically, flexibility can be harnessed from all elements of the system in combination. As presented in Figure 1, potential means to include demand response, networks, storage, conventional generation and wind and solar power themselves by curtailments; this report has a special focus on *how the electricity markets can be organised so that flexibility is efficiently tackled*, that is, the *market design* element of Figure 1 . That is, the detailed technological potential or progress of different technological measures, are not concentrated on in this report.

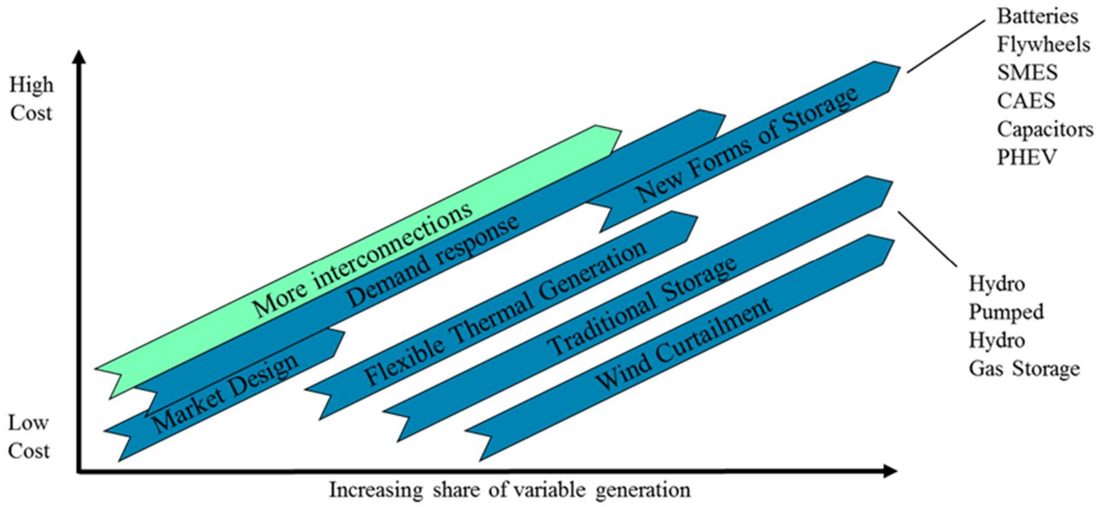

Figure 1. Conceptual sketch of different options to integrate variable generation and increase flexibility in energy systems. The positions of the options in cost axis are neither exact nor fixed in the future towards as technology develops and the situation is different depending on markets considered. (Source: Juha Kiviluoma, VTT).

What are the building blocks of market design, then? The general trends in electricity markets in the EU have for decades been towards market liberalization, integration and harmonization of rules. However, the practices in Europe – and worldwide - still vary. This, in turn, has an effect on the impact of market design on potential of flexibility resources. Figure 2 presents an overview of the different elements of power trading, a key component in market design.

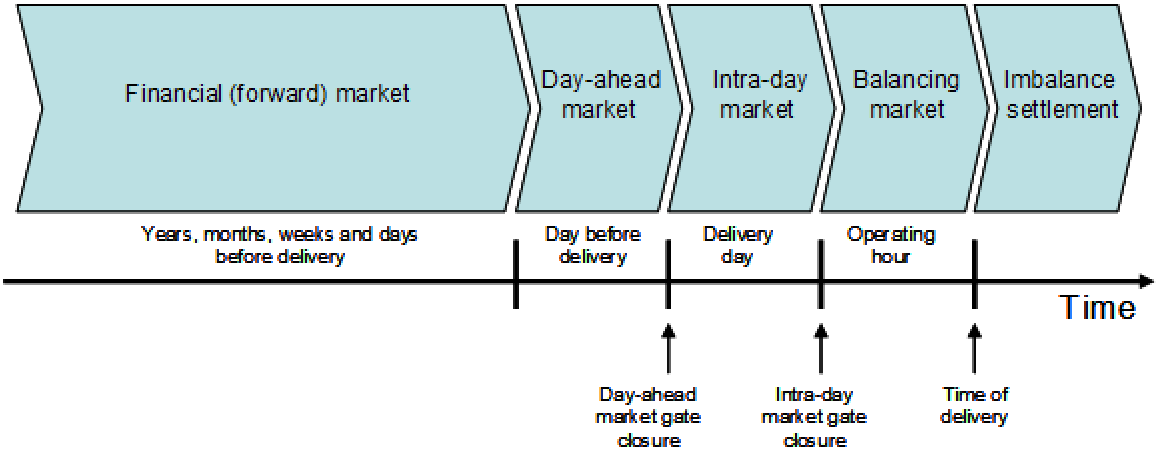

Figure 2. Structure of power trading. Gate closure refers to the moment after which the bids submitted to the exchange cannot be modified. (Ruska & Similä 2011).

The elements of power trading presented in Figure 2 vary in different markets, i.e. some of the building blocks to be considered under a topic market design. For example, time from gate closure of day-ahead market i.e. the moment after which the bids submitted to the exchange cannot be modified - to delivery can vary. In Nordic context, the day-ahead market closes at 12:00 CET on the day previous to delivery, whereas the intraday market is a continuous trading market where adjustments to trades done in the day-ahead market can be made until one hour prior to delivery. The intra-day market opens after the day-ahead market is closed.

The longer time gap specified in market design, the greater the risk for forecast errors can be seen present - either in production or consumption or both. Especially, this situation is interesting in future markets with high shares of var-RES with an additional stochastic element. That is, in such situation, the need for balancing actions after day-ahead gate closure is also greater, forming a particularly interesting segment in flexibility markets. Here, in Nordic set-up, the market actors responsible for balancing – *balance responsible parties* - can operate after intra-day market gate closure, but need then to report the contract positions to the system operator. It has to be stressed that various terminological choices exist regarding trading arrangements; it is also used that the trading segments are divided in day-ahead and real-time markets.

In considering different market designs for flexibility, we specify the term flexibility as "*the ability of a power system to respond to change in demand and supply*" as suggested by Cochran et al. (2014). Furthermore, a distinction between adequacy of capacity (responded in long-term, temporal step of even years) and flexibility (responded in operational timescales from hours to minutes or even lower) is useful in defining the targets of considerations of market designs.

Milligan et al. (2012) find that flexibility has not been tackled adequately and suggest the work in improving the market design to take flexibility into account is still in its infancy. In principle, however, current electricity market designs offer possibilities for trading flexible resources in various timescales; that is, even on a timescale of minutes or seconds. However, it has to be stressed that the shorter timeframes are often run automatically or by System operator (balancing markets or ancillary services). A central element in harnessing flexibility from the markets is the temporal resolution; that is, whether the day-ahead (or hour-ahead) market is based on hourly, 15-minute, 5-minute, or other timesteps and what are the options for market participants to trade the products of flexibility.

The fact that short-term markets are often run by System Operator and are not equipped with the highest level of transparency, however, restricts their potential *in market-driven penetration* of flexible resources. That is, the operational System Operator decisions are not generally visible for all market participants and consequently, through the market platform, only a little information for incentives to impact on actions of market participants is provided. This is also true if the balancing market prices are only published afterwards.

Table 1 presents an overview of the key dimensions of the market frameworks for decarbonisation (IEA 2016). As can be seen, there are a lot of policies and regulation choices available in order to serve the needs for market frameworks serving the objectives of decarbonisation, a key target in international and European energy framework. We find the issues under key interest in this report falling into categories of operational efficiency and reliability and adequacy. Also, points related to consumption in a form of retail pricing structures and distributed resources are of interest. There, potentially large unused potential for flexibility is available. In these areas, pricing practises and market design can be seen potential key enablers of flexibility.

Table 1. Overview of the key dimensions of market frameworks for decarbonisation. The key areas in this report are shaded. Source: Modified from IEA (2016).

Objective	Policy	Type of regulation	Competitive markets
Low-carbon investments	*Carbon pricing*	Carbon regulation	Carbon price (trading scheme) Long-term contracts
	Additional policy: support schemes	Low-C long-term support	Auctions set support level Integration in markets
Operational efficiency/ Reliability and adequacy	*Short-term energy markets*	Market rules Scarcity pricing Reliability standards	Energy prices with a high geographical resolution Energy prices with a high temporal resolution Dynamic pricing offers
	Additional policy: Capacity markets	Capacity requirements Demand response product definition	Capacity prices Demand response participation
Network efficiency	*Regulation*	Regional planning Network cost allocation	Congestion revenues Transmission auctions
Consumption	*Retail pricing*	Network tariff structure Taxation and levies	Retail competitive prices Distributed resources

It is often stated in public debate on many markets that efficient operation of markets calls for minimal interference of regulatory mechanism. While this argument can be supported by economic theory, however, according to Roques (2007) *the practical question is not whether electricity markets will deliver perfect outcomes, but whether the specific characteristics of electricity introduces* *systematic biases in market behaviour that require more complex market designs and regulatory requirements.* This statement is also valid in a context of approaching flexibility issue in the current European context. It must be highlighted that in the end of the day, setting the temporal unit for market transactions – as an hour, fifteen minute, or whatever, for example, is not based on law of nature but *set by the market rules*. Thus, dismissing market design is not an option. Market design *must* be considered and the choices made have an inevitable effect for the introduction of flexibility.

This report has the following structure: Chapter 2 discusses the general shortcomings of electricity markets in a light of recent development, considered measures and their relation to flexibility; Chapter 3 takes a market stakeholder-based perspective and analyses these problems and solutions in Nordic/Finnish context; Chapter 4 introduces and analyses a novel type of two-market system as an elementarily new type of market design solution for flexibility; Chapter 5 synthesizes the work by suggesting an application of two-market system suitable in Nordic electricity market context.

2. Shortcomings in the current electricity market design

2.1 Claims and argumentation

In this section, we consider the question of if there are shortcomings in electricity markets and how they should be tackled. We start building the discussion on elementary qualities of an electricity market design, and subsequently, move to questions more related to flexibility.

In recent years, a number of claims have been presented to justify a need for rearranging electricity markets or modifying the regulatory arrangements in place. This report was prepared in a series of internal meetings by the authors. In these meetings, a series of claims often presented on electricity markets was discussed. A goal was not to provide with direct answers but more to open up the field of research. What is actually wrong with the current– or is there anything? How could the claims be justified? Accordingly In the following, typical claims and argumentation found out in meetings are presented and described[1]

(1) *Market prices are too low.* This claim is often reasoned as follows: due to subsidized capacities with low variable costs, market prices fall. Eventually, the price level is artificially fallen beyond a level of short-run marginal costs. This causes generators making losses and capacities exiting the market. This leads to vicious circle of only subsidized capacity surviving in markets, destroying the essential idea of market outcome being determined based on free price, investment and production setting of market participants. Consequently, efficiency benefits which initially justified liberalized markets are lost.

(2) *Market prices are too high.* This argument is typically seen due to market power in electricity markets showing characteristics of oligopoly markets. The oligopolistic operation results in inefficient system from economy point of view. The problem is at it extreme during the system stress hours due to nature of inflexible electricity demand. It causes an inability of demand-side to respond to the high prices. Generators are also suggested to enjoy windfall profits. This problem is emphasized in electricity markets that have many barriers in market entry.

[1] see the complete questions and answers tables in Appendix

(3) *"Markets do not produce enough flexibility* "(or lack an essential quality of considering techno-economic phenomenon X)." This argument is related to the fact that a bulk of the power has no ability of adjusting the production in short-term but these qualities are left under a responsibility of System Operational functions. This inability of markets to not tackle flexibility may cause the system to collapse or at least to develop in an inefficient way.

(4) *"Markets do not produce enough capacity."* This claim is suggested to being related to oligopolistic nature of the market and barriers in entry. Thus, the producers' operations lead to insufficient capacity from societal point of view.

While the claims (1) – (4) have different relation to flexibility, they all can be discussed in a context of this report. That is, in a light of considering the claims (1) and (2), one has to keep in mind the general properties of the markets. That is, a move in market price always implies benefiters and losers. Thus, it becomes a key issue of how one could prove the price outcome of market being "wrong"? A straightforward counter-argument could suggest that dynamics in prices is a normal phenomenon in line with the nature of free markets. Thus, instead of arranging the market to produce "right" prices, one should rely on the free market outcome based on decisions of market participants and the corresponding ability to produce the most efficient outcome. Thus, when considering the market design, it becomes a key issue to acknowledge that one cannot preserve both a certainty of knowing prices and simultaneously enjoy efficiency gains of free market. Instead, it rather becomes a trade-off between efficiency and uncertainty related to outcome.

One could suggest that in Nordic countries during the last few years, claim (2) has been less often presented. It used to be more common in the latter half of the first decade of 2000s, a period with higher, rising, electricity prices. However, as the opposite claims can be presented by different participants, it becomes essential to discuss how the claims be argued for or against.

Figure 3 presents the monthly average power prices in NordPool power exchange under period 2005-2015 in Finnish price area and system price, respectively. We can observe the downward trend since 2011, as the price level has even reached 9.55 €/MWh in July 2015, however, more often varying between the levels of 20 and 40 €/MWh.

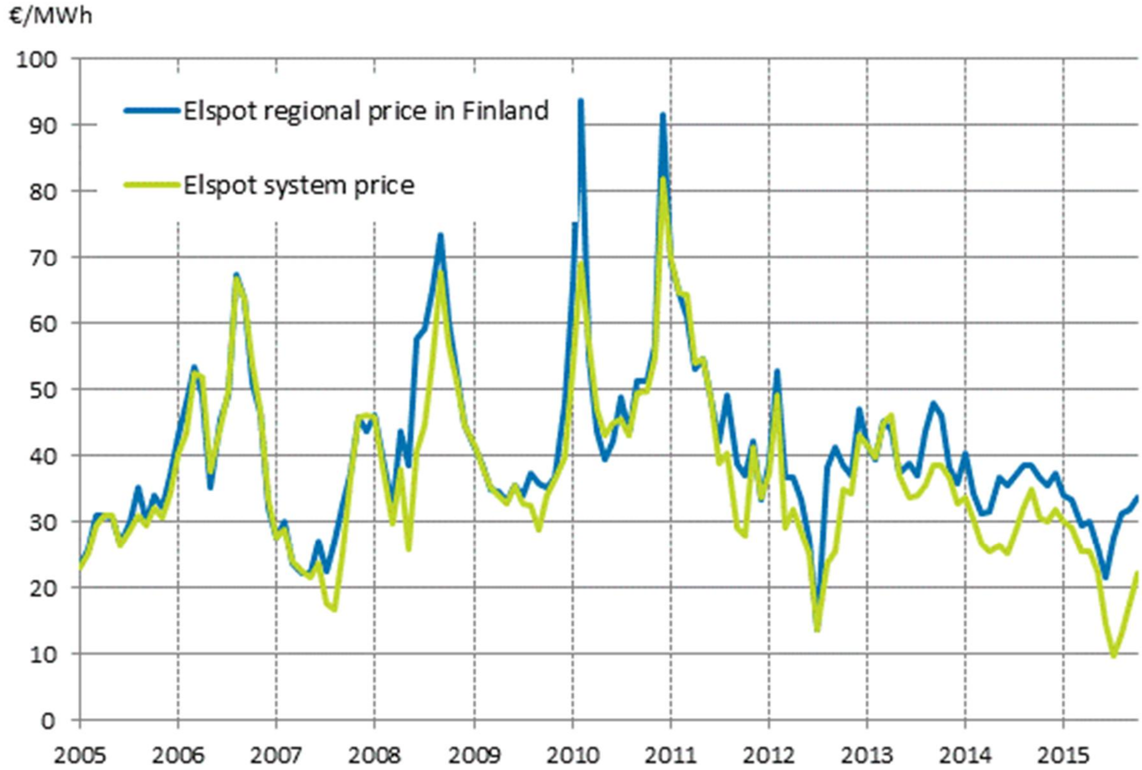

Figure 3. Average monthly spot prices at the Nord Pool Spot power exchange. Source: Statistic Finland, http://www.stat.fi/til/ehi/2015/03/ehi_2015_03_2015-12-14_kuv_006_en.html.

In a light of the price development during the last few years, it is natural that recently, the discussion in Nordic countries seems to have been more related to the “too low” prices argument, and thus more concentrated on in this report, too. The claim could be supported by the fact that production costs, in the long or short-term, are not covered. In the opposite (“too high”) situation, the argumentation could build on the power producers making extraordinary profits. If this would be argued by monopolistic behaviour, the competitive analysis could build on established methods and indicators such as HHI, market price simulations, etc. On the other hand, high prices could be argued to reflect a normal phenomenon in the markets and signalling of capacity deficit. High profits can be argued as not being extraordinary as being resulted from power producers’ right strategic choices

The claim (3), *“Markets do not produce enough flexibility*“, has a straightforward relation to the goal of this report. In the extreme, this claim being true could put the system security in danger. The relevancy of this claim could be analysed in different situations by simulations of extreme cases by independent system operators/regulators. On the other hand, one could argue that one should not interfere with the markets as the market mechanism produces enough flexibility in the market. Consequently, flexibility characteristics should be left under the responsibility of System Operator who uses appropriate tailor-made market mechanisms.

The claim (4), “*Markets do not produce enough capacity”* can based on capacity sufficiency seen threatened based on simulations. However, a counter-argument on relying on markets leading to optimal amount of capacity can be suggested. Relying on elementary qualities of market economy, it can be argued that minimal interference in market mechanism leads to maximal benefit from societal point of view. Also, suggested capacity insufficiency can be seen to being tackled by markets, with a note on inertia in capacity expansion also being a normal phenomenon. The problem can also be seen to have primarily been caused by feed-in tariff schemes having a dampening effect on prices. Hence, the target of claims of improper market arrangements can be turned to unsustainable support mechanisms instead of market design.

2.2 Suggested solutions

Assuming that we'd find it justified to make a reform in markets, it'd mean we'd have to consider measures presented in Table 1 in a light of current market design and define a proper mix for reforming it. However, the discussion above suggests that it may be difficult to unambiguously justify if a certain electricity market design is adequate or not. That is, in most cases, one can always find arguments for and against on the question whether an additional solution to market design is needed or not.

The reason for difficulties is due to the fact that one cannot separate the effects of all the market fundamentals affecting the market separately. For example, if we observe a period of low prices, it is not easy to judge whether it signals of fundamental flaw or just reflects overcapacity in the market as a normal phenomenon. However, if the "leave it to markets" solution is assumed to not being adequate in general, at least the following solutions have been suggested or used as correcting measures in different electricity markets. They are further discussed in remaining parts of this report.

Table 2 presents solutions suggested to improve electricity markets designs based on this study. The introduced solutions are considered mainly from Nordic perspective, and their consideration in a light of flexibility related questions. It is of notice that the measures considered do not only deal with wholesale markets but the electricity system as a whole.

Table 2. Solutions suggested to improve electricity markets designs, mainly from Nordic perspective, and their consideration in a light of flexibility related questions.

Solution	Flexibility related question/observation
Capacity mechanisms	*How do the capacity mechanisms consider the flexibility qualities of capacity?*
Increase flexible components in market systems o **15-minute markets (or even shorter)** o **Pool with centralized optimization of flexibility resources**	*Do the market system alterations suggested consider options and impacts brought by technology, especially demand side?*
"Two-market design"	*Incentivizing demand-side to participate in flexibility markets*
"Platform markets"	*Incentivizing small players in the market*

In a light of considered market reform needs, it is particularly interesting to review a public consultation on development needs of electricity markets launched by the Finnish System Operator in Spring 2016. As forthcoming actions, the System Operator has announced the following development testing actions (Fingrid 2016):

- Nord Pool pilot gate closure time of intraday markets to 30 minutes
- A pilot of publication of real-time price in balancing power markets in scarcity situations beginning in November 2016
- Two pilots on third-party participation in reserve markets
- 5 MW bid size possible, if electronic subscription in place.

Interestingly, many of the actions have targets similar to those discussed previously in this report: shortening the gate closure, increasing transparency in balancing power markets and allowing smaller units to participate. Accordingly, the course of action considered by the System Operator seems to be in line with the international discussion regarding flexibility integration. It remains to be seen whether the actions are sufficient to cope with the forthcoming challenges.

2.2.1 Capacity mechanisms

Capacity mechanisms are one internationally recognized option for regulatory requirement or intervention to tackle the shortcomings of energy only-market. As a novel element, there are a lot of recent reviews and discussion on the issue, see e.g. Koreneff et al. (2014) & (2015). Typically, capacity mechanisms are considered to address the capacity adequacy problem in the longer term, that is, even over a period of years. The necessity of capacity mechanisms has been under a debate for a long time. The debate appears not to have been started only connected to recent debate on RES-E, even though this might have had an enforcing impact. In this report, the studied needs for market to address flexibility bring an additional element for capacity mechanism design. It is interesting to note that in a historical perspective, the capacity mechanisms have been discussed long before the var-RES-E production came into play on a major scale in Europe.

The discussion of capacity mechanisms has been built on stated central problem in electricity markets. That is, with adequate generating capacity, electricity prices are seen as too low to pay for adequate marginal capacity. A natural question arising is that why are not such mechanisms discussed in car markets, food markets, raw material markets, etc., then? This is usually explained by electricity market characteristics related reasons:

(1) lack of price-responsive demand,
(2) limitations in storing the product,
(3) vulnerability to market power during times of high demand.

The problems mentioned before are "old", however, their consequences have potentially worsened due to the massive take-up of subsidized RES capacity in Europe during the last years. Thus, it is in the interest of this report to study if - and how - the capacity mechanisms consider quality of capacity and opportunities of new technology that could bring flexibility into the pool of options considered.

The capacity mechanisms can be divided in targeted volume-based mechanisms and market-wide mechanisms. Volume-based approaches principally aim to compensate reserve capacities outside the markets, whereas the market-wide allocate the compensation to all the parties successful in the auction. Several models have been discussed and introduced worldwide and in Europe.

- **Capacity payments**: administratively-determined compensation for having a capacity available. (experiences: Spain, Ireland + Northern Ireland)

- **Strategic reserves:** “light” solution. Peak load capacity procured by authority and kept outside markets in normal situation. (experiences: Sweden, Finland)
- **Capacity requirements:** administratively set requirement for retailers of large consumers to meet. Experiences; USA, typically an order of 15 % reserve margin above estimated peak load
- **Capacity markets.** Marketplace for capacity units, several designs and choices
- **Reliability contracts of reliability options.** Financial version of capacity requirements.

In Nordic context, the wholesale market is based on energy-only design, with special arrangements for reserve power (capacity). The recent experiment for a capacity market in UK, first run in late-2014, thus provides elements for a good case study. This is due to following reasons

- The model in UK is built on current market circumstances. These are radically different from those of the 1990s, for example (technology development, climate and energy policies of EU, growing shares of renewables, etc.)
- The design process in UK has had an opportunity to build on actual experiences on capacity mechanisms implemented during the 2000s.

The recent experiment implemented in UK since the late-2014 basically has elements in bringing flexibility (Koreneff et al. 2015) in markets. That is, new entrants, alongside with demand side resources (DSR) resources will be classified as price makers, and they are free to bid up to the overall auction price cap (75 £/kW). Also, there is an element of responding the system needs in temporal sense. That is, in the British Capacity mechanism, ”Capacity warnings” are declared by system operator 4 hours before delivery. In case of non-availability, penalties are obliged to participants who hold capacity commitments. (Koreneff et al. 2015). The design as such has elements of aiming to ensure capacity adequacy from System Operator’s perspective during peak load hours. It does not seem to have built upon giving market-based incentivizes for participants for supplying or demanding flexibility as in claim of shortcoming (3). Thus, this function seems to have more or less been left under a responsibility of System operator.

During its first two years of operation, the British capacity mechanism has been criticized of not bringing enough new capacity in markets alongside with. According to a report by National Grid (2015), as a result of the first T-4 auction concerning winter 2018/19, British Government purchased 49.26 GW (derated) capacity. Of this, 64% was existing capacity, 14% refurbishments, 16% pre-refurbishment. Thus, ‘only’ 5% was newbuilds, and 1% demand-side resources. In a light of free markets, however, it must not be considered as a law of nature that there is always a need for new capacity; it remains a possibility that no such capacity is needed due to market circumstances. However, despite having a demand-side element possible, the results have not been encouraging in a light of attracting demand side resources in markets, despite often presented as being positioned high in the cost efficiency comparison. In general, this claim can be supported by the low level of investments required. Hence, it seems probable that the potential of demand side is not fully reflected in the British-type capacity market and a more fundamental is solution is seeked after in the following. *The two-market solution* presents a novel type of idea to harness the potential of demand side in markets more efficiently (see a separate Chapter).

2.2.2 Short-term markets

Short-term markets are proposed for several upgrades by IEA (2016) to cope with the challenges brought in by decarbonisation. There, it is suggested that intraday and real-time markets could be improved according to the following principles:

- high geographical resolution to more accurately price congestion;
- use uniform prices for all real-time energy used for balancing, in order to reflect the marginal costs;
- be updated continuously during the last few hours before operations, reflecting improved forecasts.

In a context of this report, the network issues, such as congestion in the first point, are not concentrated on. In contrast, two latter points have significance.

In Nordic countries, TSOs of each country have a pre-set set of reserve obligations. They procure and services in a manner they consider the best to meet these obligations, noteworthy, trade between countries is allowed. In Finnish context, intra-hour balancing market is driven System Operator. In this market, balancing power bids that are able to 10 MW power change in 15 minutes, can be offered. These bids are given to System operator no later than 45 minutes before the use hour. In addition, there are following short-term products of in market product palette run by System Operator, mainly used for control of frequency. [2]

- Frequency Containment Reserves (FCR),
- Automatic frequency regulating reserve (aFRR),
- Manual Frequency Restoration Reserve (FRR-M).

2.2.3 Reliability, availability and scarcity pricing

Electricity industry is in special position in terms of scarcity pricing. Due to traditionally present lack of demand-side interaction for technological reasons, it causes an extra challenge to value reliability during scarcity hours. Using conventional technology, the lack of demand-side to value reliability, is evident. For interested readers, we refer to Koreneff et al. (2014). Furthermore, during scarcity hours, a threat of market power abuse is particularly high. Hence, an appearance of regulatory intervention is often suggested. The role of increasing var-RES puts some extra requirements for this, as the availability of wind or solar power during the system peak load hours is not self-evident.

It can be shown that the social cost of market failure – defined as a situation in which supply and demand do not match, market price is not defined and demand has to be curtailed to prevent the breakdown of the system – can be minimized by capping the electricity price at the average value of lost load (VoLL). This will not prevent service interruptions but limits them to an economically efficient duration (de Vries 2004). This is a second-best outcome (Koreneff et al. 2014). However, the value of VoLL is not only difficult to value but can reach a level of dozens of thousands of euros (IEA 2016). Thus, it is problematic to allow such a high price levels with vulnerable demand side.

[2] http://www.fingrid.fi/en/electricity-market/reserves/acquiring/Pages/default.aspx

As the electricity markets fail to achieve a standard of reliability, this is typically implemented by tailored process of regulator or System Operator. According to IEA (2016), typical reliability standards applied have somewhat appeared 10 % or 15 % above capacity needed to cover peak load. However, it is of notice that with high levels of solar and wind, traditional measures might prove insufficient to produce the optimal amount of reliability.

Tackling the problems presented above, IEA (2016) suggests the scarcity pricing should be implemented with the following measures.

- high price caps, often above existing ones, consistent with reliability standards
- *ex ante* market power mitigation
- some form of regulation of scarcity price formation during system stress.

Furthermore, IEA (2016) concludes that in addition to scarcity pricing, some sort of capacity mechanisms may be necessary to create a safety net during the transition to low-carbon power system.

3. Essays on electricity markets

3.1 Do we need capacity mechanisms in the Nordic market or in Finland?

As has been presented in this report, there a lot of different types of capacity mechanism out there already. We have a so far functioning market mechanism, an energy-only market, in the Nordic countries. Supporting points: dynamic price development with low and high periods, no capacity shortage, and roughly speaking, the market price is in line with short-term marginal cost. Is it enough, or do we need more? When we discuss energy-only markets, the missing money is often mentioned. The price setting in a well competitioned energy-only markets is based on short-term marginal cost of the marginal producer. Where will the marginal producers get revenues to cover their fixed costs? This problem is actually solved if demand response functions as a price setter. And, even the Nordic market is not so pure an energy -only market. Finland and Sweden employ strategic reserves. Renewable power enjoys support schemes such as green certificates (in Norway and Sweden) and price guarantees (Denmark and Finland) that effectively work similarly as capacity mechanisms.

Fossil based regulating power plants such as condensing power plants do not enjoy such support schemes in general, but are threatened by low electricity prices, to an extent where several plants have already been closed down. Is the low electricity price a problem, and in addition, how big a problem is the closing of regulation capable condensing power plants?

3.2 Is the low market price of electricity a problem?

To understand the implications behind the question, we must look at it from different viewpoints. But first of all, we need to understand what we include into the term “market price”.

From an end-user market price perspective, a low price is a problem only if sellers' costs are not reimbursed, or if there are secondary agendas. The government might want to improve energy efficiency and for that sake increase the value, and thus the price, of electricity. On the other hand, as improved energy efficiency is expected to go hand in hand with an increased use of electricity due to energy use conversions, for example from oil heating to heat pumps or from gasoline cars to electric vehicles, lower electricity prices would be beneficial.

End-user price levels do not directly correlate to wholesale market price levels as can be seen in Germany and Denmark (Eurostat 2016), where we have the highest household end-user prices in Europe, despite low market prices. Industry end-user prices can and do, in turn, differ from household end-user prices. According to a study by Pöyry (2016), large energy-intensive industry pays lower electricity prices in Germany than in Finland, if we take tax refunds and price compensations etc. into account.
We will here look at the problem from the perspective of a low wholesale market price and the Nordic and/or Finnish market.

3.2.1 Retail market perspective

As already noted, low wholesale market prices are not a problem per se for the retail market. Sellers take their profit from the margin they add to the wholesale price, so the price level itself does not form a problem in the long run. Short term problems for the seller might exist if wholesale market prices are rising, not falling, and the tariffs are lagging behind, but that is anyway more a problem of setting the margin and for risk management. And tariffs will more and more be dynamic in the future, and, for example, be based directly on the area spot price, reducing the risk for sellers.

As for the end-user, it might not be as important to watch over their energy use as with high prices, but less expenditures does give more money in hand and might thus encourage energy efficiency investments (but also the reverse). A high end-user price would be a much better incentive for a customer's own electricity production, especially photovoltaics, but a) the whole market price forms just a small part of the whole end-user price, and b) artificially high prices (taxes and levies) result in, from the system perspective, suboptimal investment decisions as can been seen, for example, in installations of electric storage batteries in PV-furnished homes in Germany.

3.2.2 Distribution system operator (DSO)

The wholesale market price has only minor effects on the DSO, as it isn't actively involved there. The main benefit of low prices is the reduction in the expenditure on losses. Low prices may also have a slowing effect on local PV and wind installations, which may at some locations benefit the already burdened net.

3.2.3 Power producers

A low wholesale market price affects the income of power producers straight. The profit margins of existing hydro and nuclear producers decrease, but as they have low operating costs, they have a good chance of remaining profitable. Of course, a high taxation such as the Swedish nuclear power tax together with low market prices and high demands for refurbishments do drive old nuclear power plants out of business, but that is more a political decision and goal. The recent mind change, in summer of 2016, of the Swedish government concerning the decrease of the nuclear tax will help keep old nuclear plants on the market. However, there has not been any reverse news from those plants that have already announced their closedown. New investments are hard to achieve anyway because of licensing and permit issues and lack of free resources of hydro (except Norway).

Existing CHP producers make less profit, but the operation is still income bringing. Natural gas based production is especially hard affected, but they are in trouble anyway because coal is much more competitive at the moment, and large gas using cities like Helsinki, Tampere, Vantaa, Espoo have a multitude of alternatives. New investments will be scarce. Coal is politically abhorred, natural gas is expensive, and biomass is a more local alternative, if price is relevant.

Condensing power plants operating in the margin are not affected by the low power prices per se, as by assumption they operate at or near variable cost, but by the low need for them. If variable power production from renewable sources increases (never mind how) as much as governments target, there will be little need for energy from condensing power plants. Calculations by Koreneff et al. (2015) show that the demand for condensing power in the Nordic market might well decrease to 4 to 6 TWh by 2035. In the long run, fossil based condensing power is not a desired alternative for electric energy production without CCS due to climate change mitigation. With dwindling peak load hours, many existing plants do not have enough margin to cover for fixed costs, and will be closed. A higher wholesale market price level would not be that beneficiary unless it involved more high price peaks.

3.2.3.1 Wind power and PV

As for all power production capacity, low prices do not incentivize investments. Nevertheless, as end-user investments are operating in a different market environment as large-scale wholesale market investments. With the sum variable price component of end-user electricity tariffs in the vicinity of 100 €/MWh (with overall costs of around 150 €/MWh), investment in PV is becoming more and more tempting, and even more so in Germany or Denmark, where the average end-user cost supersedes 300 €/MWh and where the energy yield of PVs is slightly better. The cost development of especially PV (see Vartiainen et al. 2015), but also wind, can be very advantageous, making them a very competitive alternative.

For many years now, wind and PV has been the capacity that is increasing the most in the world each year. If it is increasing on its own, fine. Then the market will reach a balance as additional capacity will mostly lower the revenues for similar time-correlating production.

If, however, wind (or/and PV) is subsidized to an extent where new capacity increase is strong, it will also add to the fluctuation of the market prices and reduce the capacity factor of regulating power plants. The more variable and uncontrolled renewable power capacity is added, the less regulating power plants can be profitably operated, although they will be more and more needed times of windstill/darkness. So, if low market prices are induced through measures outside the market, that will present a problem.

3.2.4 Market operation perspective

Any kind of new power capacity investments will have a tough time to be profitable when market prices are low. Low market prices are, however, an indicator of a surplus situation in the power balance, either due to decreasing loads or increasing production or both. We do have enough capacity at the moment, so we do not need new capacity soon. As old capacity is closed down because of age, emission directives, unprofitability, we will need new capacity at some point. If support for renewable power production continues, e.g. green certificates, feed-in tariffs or price guarantees, we will get new power capacity.

Demand of electricity is expected to increase, if not else then because of new load instigators such as electric vehicles and heat pumps. Whereas appliances are getting more and more energy efficient and energy efficiency is expected to continue improving, also the application numbers, sizes and types as well as energy source swaps have an impact, many times adverse, on electricity savings. However, as research (Laitinen et al. 2011, Ruska et al. 2010, Koreneff et al. 2009) has shown, heat pumps will not necessary increase the total demand that much as they have a decreasing effect on direct electric heating load, and even one million electric vehicles (full electric vehicles and plug-in hybrids) increases the total demand by less than 3 TWh.

To what extent will we have energy intensive industry left in the future? That is a question for politicians and the EU involving a lot of question such as how to treat the sustainability of Nordic bioenergy. Anyway, low wholesale market prices are beneficiary to industry. High prices, in turn, might become an obstacle difficult to overcome by the energy intensive industry. High prices reduce the demand at least on a longer term and vice versa for lower prices.

From a market point of view, low or high prices are normal drivers, not a problem. However, at times of scarcity, prices tend to rise, but is life, and politicians, ready for expensive electricity? From a flexibility point of view, really high price spikes are a powerful driver towards demand response, especially if the end-user can feel them with spot price based tariffs.

3.2.5 System operator

Low wholesale market prices are not a problem per se, but if condensing power plants are lost, do we have enough flexibility to uphold the power system at all times? Well, there are not that many condensing power plants up and running as we speak. The FLEXe research program offers an abundance of opportunities for alternative flexibility such as demand response and energy storages (including using district heating systems for flexibility), which are already implemented to some degree. District heating networks were already in the 1980s used for flexibility, with electric boilers and auxiliary heat storages. Denmark has also already (re)started to use district heating for flexibility in the power system in response to growing wind power production figures. Demand response by large end-users is in use for very different time steps, from long term responses of the aluminum industry to instantaneous shut offs of uses in the pulp and paper sector etc.

As households in the Nordic countries use electric heating to a large extent, this offers massive demand response potentials. And it has already been put to use due to day-night-tariffs. More dynamic are also easy to implement: for example, the energy utility of Helsinki, Helen, charges selected electric heaters according to the spot price (Koponen & Takki 2014); Fortum has piloted the use of circa 70 households for the balancing power market (Fortum 2016).

The artificially low market prices, if uphold for a longer time, will lead to a deficit in power plant capacity. And capacity is needed the most during times of peak load. If we allow for high market prices during peak load times, we will be able to muster serious demand response capacity, if the demand is allowed to feel them and technological prerequisites are in place. If not, there might well be problems. So, low prices are not a problem per se, the problem is perchance more in the category of stale and stiff end-user tariffs impacting the preparedness for flexibility by end-users.

Ancillary services might also have difficulties getting enough offers, if there are few regulating power plants up and running. Of course, with higher remunerations, plants not partaking in the ancillary services might well change their configuration and behavior. New (bio and perhaps peat based) CHP plants will perhaps not be of the backpressure type, but extraction power plants, unbundling the power production from the heat demand. Demand response, if properly operated, will also be able to throw itself into the ancillary services.

3.3 If our condensing power capacity is closed down, will our energy-only based market model be enough and will our power system survive?

The buy and sell part of the Nordic electricity system, the wholesale and the retail markets, does not have a guarantor, that is, someone making sure there is enough generation capacity to match the demand. If you want to use electricity, you have to find someone who sells it to you. Of course, there is always the problem of balancing as the demand (and more and more of the production) is stochastic by nature, but for that we have the balancing market and balance settlements.

The operation of the power grid on a millisecond or minute scale is another issue and not part of the energy market. Here, the question is of having enough ancillary services to be able to uphold the power system according to set quality criteria (frequency, voltage, etc.). Here the system operator, in Finland Fingrid, has the responsibility.

3.3.1 Wholesale and retail market perspective

The basic structure of the Nordic market relies on balance responsible parties making sure that each consumed MWh has a counterpart in their balance. If not enough generation is offered on the spot market, the market price reaches the ceiling (at the moment 3000 €/MWh). This results in curtailment of the demand side. The curtailment in the affected price area is divided among the affected buyers pro rata based on their wish for purchase at maximum price. In Swedish and Finnish price areas, strategic power reserves are in use in the winter months. They are active in the spot market at a price just above the highest commercial price. In the future, this price could be changed to the maximum price. In Finland, a small part, 10 MW, of the strategic reserves consists at the moment of load shedding by a district heating heat pump.

The dimensioning of the strategic reserves is such that the power system should be able to avoid brownouts or blackouts. even as condensing power plants have been closed down in recent years, the strategic reserve capacity has dropped in ten years from 600 MW to about 300 MW. Closing of condensing power plants has not resulted in problems. Even during the new highest load ever in Finland, observed on January 7th, 2016, 15 100 MW, strategic reserves were not employed.

If and when the demand increases and more old non-intermittent power plants, e.g. nuclear power plants, are closed down, the situation might differ. There is a risk that there will not be enough offers for the needed capacity amount of strategic reserves. Ramping is another issue. As intermittent or exogenously variable production fluctuates a lot, there might be large difficulties to find regulating capacity that is able to react as steeply as is need. On the other hand, as has already been proved, demand side can also be active in the strategic reserve auction.

At peak prices, it would be beneficial if all end-users showed price elasticity as an alternative to other sources of flexibility resources. We need dynamic and spot price based tariffs for this to happen, and in connection with this, changing the strategic reserve price setting to the max price would further incentivize demand response. Dynamic, spot price based tariffs would also be a great help in decreasing the need for ramping generation. If demand follows the price, and thus the intermittent production: problem solved. Well, except of course for the forecast errors and resulting balancing issues, but if we allow for more and more demand response to partake in the balancing market, the backlash will be smaller.

The question is, will Finland be able to balance the system during cold and wind still winter days and evenings? Well, new electrically heated houses are supposed to have alternative heating sources. With high enough market prices (that the end-user also has to feel), daily and even weekly load shedding will be seen. The industry has also a high demand response potential. And it doesn't even have to be automated. Whereas house owners can't be bothered to manually schedule their heating according to spot price day in and day out, they can and they will make the decision to warm with wood occasionally. Are Nord Pool spot offer alternatives versatile enough to encompass electric heating demands? We know approximately the heat demand load for the next day (as it mostly is filling up the storage), hourly load maximum, storage capacity, state, and charge and discharge loads, and how much is cumulatively needed by which hour, but can this information be formed into price elastic offers for the next day that, when the auction is cleared, amount to the needed loads? And for electric vehicles? Or, we make a buy offer for a basic load pattern and use the demand side flexibility in the aftermarkets or the ancillary services.

3.3.2 Generation alternatives

New CHP plants will perhaps not be of the back-pressure type, but extraction plants (see Danish CHP or Pietarsaari) with a high power production flexibility. And the heat production in a CHP can flex down, if that is needed, as heat can be produced by other means, i.e. heat boilers or even electric boilers.
Wind power plants can also be run below their calculated output to be able to up-regulate when needed. This of course comes with the cost of lost generation. There are also PV installations in Germany having been regulated to have inverter capacities that are clearly below the solar panel nominal output[3]. Also this comes with the cost of lost generation, but as there are savings on the inverter side, the overall profitability might even improve, according to Pasonen & Hoang 2014.

Money can buy reserve power capacity. As we have a party with a clear responsibility of upholding the system, if other choices are all used, there still is the alternative of new reserve capacity, if the situation becomes serious. Gas turbine plants are fast to build, and the money can be gathered from the transmission grid tariffs. However, the governmental target to get rid of all coal plants is like picking a fight, if there are not enough substitute regulating resources available and usable before that. To make this possible, market rules might have to be changed, and above all, occasional high prices should not be abhorred but applauded.

The question is, is it wise to demount condensing power plants now if we need them in five or ten years? But then the system should – through some mechanisms – pay the utilities for keeping the plants operational if they cannot be remunerated through normal spot or balancing market trade. Actually, that is what the strategic reserves are all about, but their time horizon is just a few years ahead.

3.3.3 System operator perspective

There are serious threats ahead: loss of inertia, loss of regulating capacity, loss of capacity for meeting peak loads, need for steeper ramping qualities of regulating actors due to more intermittent (and less easily forecasted) production.

The problem is on the other hand easier to solve, as we have a responsible system operator, and the system operator has ways, transmission tariffs and bottleneck incomes, to remunerate the actions

[3] German VDE standard.

taken. Some solutions will be more expensive than others, but mostly the ancillary services will be paid by the end-users.

Demand response is also not the only alternative to “missing” local generation. Increasing the transmission capacity and especially cross-border transmission lines helps a lot, both for ramping needs and for peak loads.

Preparedness solves most things or at least decreases the problems. To be prepared, we need good forecasts. If we know that the power output from wind and solar will drop dramatically during a given time space, we can have all (fossil) plants up and running at minimum load well in advance, we can prepare loads for downsizing and we can have wind (and solar) operate at a lower production level just so that they will be able to temporarily uprate fast or just to restrict the drop.

We also need active market participants and suitable business models and a level playing field in order to efficiently solve the flexibility problems. For example, is fast frequency containment by end-users more a business case problem than a technical or economical problem?

3.4 Summary and conclusions

The Nordic energy-only market has a lot of tools in “its back pocket” to manage the problems arising from increasing amount of variating renewable power, low energy prices and an imminent loss of regulating power capacity. As new capacity is clearly more expensive than existing capacity, we would be well advised to extend the strategic reserve studies to 2025 and 2030.

As the Finnish power system configuration is in general, it is not a bad idea to prepare a wide and diverse palette of means to answer the future demands for regulation capability and ancillary services. Capacity mechanisms might become necessary in the future. If we, however, add a lot of subsidized varying renewable energy production capacity, we can’t depend on regulating capacity staying on the market without support. Here strategic reserves seem to be cost-effective solution, but the question arises, would it be wise to extend the study horizon a bit further.

As demand response is among the most cost-effective tools we have to master many of the problems that the future will bring, we should start to remove possible regulatory or market configuration type of barriers as soon as possible. New demand response type of offers for Nord Pool, if we could find a way, could have an impact in the furtherance of end-user flexibility.

4. Two-market design

4.1 Introduction

The marginal cost of producing one additional unit with the variable renewables (VRE), i.e. wind power and solar PV, is zero – typical feature of the economies of the internet. This lead to a fixed price world. It is a capacity, not energy, market: energy from units of zero marginal cost technologies is effectively costless, as is use of broadband networks most of the time. In such a world everyone needs fixed priced capacity contracts (Helm, 2015).

On a yearly basis, the production of a unit of VRE capacity does not alternate much - or expressed in another way: the load factor remains fairly stable from year to year - but on daily basis the variability is large. This is similar to outdoor temperature: yearly average temperature in any place is a relatively stable but average daily temperatures show huge variability. This feature can be used in product pricing.

The relative share of VRE capacity decreases the flexibility of generation. At the same time the potential flexibility of the demand side has increased due to the developments of the IC technology. What is missing here is the incentive to transform that potential into an operable state, to make both sides of the market to move with the same rhythm.

4.2 The two-market system

This section presents an innovative approach that is intended to solve the problems identified above. It is an electricity market design suggested by Malcolm Keay from OIES (Keay, 2016) and it is thought to upgrade the UK electricity market design.
To be successful any new design has to do the following:

- incentive customers to be flexible
- accommodate zero-marginal-cost technologies
- have a vision on how to get rid of economic support for the zero-marginal cost technologies
- incentivise timely capacity investments on flexible generation forms
- produce price levels that make the system sustainable

These are challenging requirements for a design to fulfil. The two-market system tries to do it by creating – as the name says – a second market for the zero-marginal cost inflexible generator forms. These two markets produce two different products for a customer to choose from. The products are firm and non-firm power. The last mentioned product is available when the (low-carbon, VRE) generators participating the non-firm market are able generate. This product is available at low cost compared to that of the firm product that is available on demand. It corresponds to the product of the present supply system. This section presents an innovative approach that is intended to solve the problems identified above. It is an electricity market design suggested by Malcolm Keay from OIES (Keay, 2016) to upgrade the UK electricity market operation.

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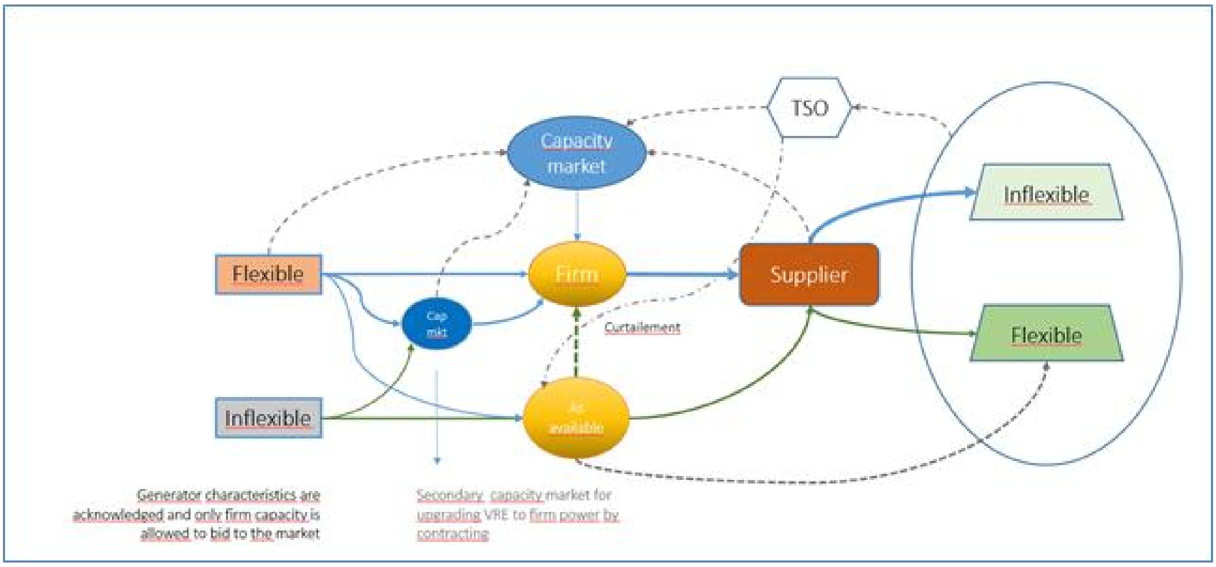

Figure 4. Principle structure of a two-market system.

Both the supply and demand side have various agents with different characteristics. These are taken into account and used as essential features.

4.3 Electricity end-use

TIn the basic retail pricing model (Keay, 2016) it is assumed that a consumer makes both firm and non-firm power contract corresponding her maximum demand (or connected load). All the loads of a customer are then behind one meter. Then consumers would receive the non-firm price so long as that generation exceeds the demand of that class and have their prices calculated as a share between the two markets at other times. For example, when half of generation comes from the non-firm sources, consumers pay half the higher price and half the lower price. The contract may have other features as well, like automatic cut-off of certain loads, when the price rises over a defined upper limit. Each customer in the two product class has the same price in each hour but the total cost of electricity is dependent on the hourly use pattern. It changes from customer to customer.

The lower price works as an incentive to use the non-firm product. But it is available only when weather conditions allow for its generation (if it consists only of VRE generation). A prerequisite for its use is that a customer has an hourly meter so that the price of electricity for each hour can be calculated.

To be able to adapt to the availability of the lower price product by e.g. storing it for low availability periods, one has to receive information on its availability and automatically control some loads. Actually, to promote flexibility, this capability of being able to receive information and control loads accordingly could also be defined as a prerequisite for obtaining the non-firm power contract. It would be natural to base the information on availability on a day-ahead market results, and then the retail customers could plan their electricity use accordingly. Real-time operation would, however, be a lot better option from the system point of view. These can coexist.

For larger loads, like electric boilers or heat pumps for district heat production, the control could be based on real-time data and these loads could as well participate to all the short-term markets as well.

These loads would naturally form an easily controllable flexibility. The prerequisite for these to penetrate the market is a level of certainty on the availability and price of the resource to make the investments profitable. The creation of the market for non-firm electricity is just the kind of factor that stabilises the economic environment. So it is not only to meet the existing demand but also to create new demand that can make use of the lower price by adapting to the availability features.

If a retail customer had two meters, then she could connect only flexible loads to non-firm meter and all the other loads to the firm meter. This makes sense if the expected economic rents are large enough.

The network connection forms a natural upper limit for the contracted power. Only if a customer can fully adapt to the variations of non-firm product can the share of non-firm power make a full 100 % of the end-use. Installing a storage may help in increasing the share but depending on the interplay of availability and consumption characteristics, a high share may be attainable only with a high connected capacity. The distribution network services will be sold in the future by fixed priced capacity contracts or at least the share of fixed cost will rise. This feature gives an economic upper limit for utilizing as available product.

4.4 Wholesale power markets

IIn the two-market system there are two connected power markets with distinctive features. Both of the markets are open to all generators that fulfil the requirements to enter. The first market is called firm and the other non-firm market. The two markets have specific roles.

4.4.1 Non-firm market

The non-firm market is open for all energy generators, firm and variable, but it is intended in the first place to those generators using zero-marginal cost technology, i.e., wind power, solar PV, etc. The product (energy) is available when the circumstances allow its generation. By forming a second market the original spot-market regains the original features as a place for firm and flexible energy.

At present, the variable renewables enjoy feed-in tariff and to develop the second market these support mechanisms may well be needed. As long as support is given the price in this market is set by a regulator on the basis of the expected long-term marginal cost of capacity. Economic support would fulfil the possible gap between the present and future costs of capacity. However, the aim in the long run would be that generators would be able to sell directly to this market without any economic support just like in any market. The price would then reflect the equilibrium between supply and demand, it would depend on the customers’ valuation of the product.

The size of this market is dependent on consumers’ ability to use intermittent power. General belief is that the potential is large but at the present there aren’t strong incentives that would make the potential operational. By creating a market to produce a lower cost product could be the step towards more flexible end-use, that would adapt naturally to changing generation of the zero-cost technologies.

4.4.2 Firm market

This is like the original spot market, but open only to those generators having flexible generation technology. VRE generators can also enter to this market by upgrading their product by contracting with a flexible generator making the hybrid to operate as a firm and flexible unit. A secondary capacity market may develop to fulfil the capacity needs of the VRE generators entering the firm market. In this way the decision of the amount and quality of the flexible capacity that can upgrade variable generation into firm power is decentralised to those agents that really know what is needed to make their technology flexible. This approach uses informational efficiency of a market over a centralised operator. and avoids the situation in which a system operator would organize an auction for capacity with various classes of specific flexibility characteristics.

Additional capacity mechanisms can be taken into use if the amount of capacity would not otherwise rise to a level needed to secure delivery with an acceptable probability. The pricing mechanism in this market has to planned in such a way that the wholesale price would cover all generation costs for all the generators. These costs and all the other system costs would in turn be passed on to consumers. The retail price of this 'on demand' electricity is higher than the 'as available' electricity.

4.4.3 Market interaction

There are only one network and one system operator meaning that non-firm power has to be dispatched together with firm power. Dispatch in the non-firm segment would be automatic except in cases where curtailment has to be applied. It is assumed that the original demand adapts partially to the non-firm generation so the demand for flexible power is less variable than without the non-firm product.

4.5 Simulating the two-market operation

A simulation model has been defined to study the functioning of this two-market design. The prime motive for the two-market definition is to solve the challenges the increasing amount of wind and solar PV capacity bring about to the present power system and markets. There are three basic cases: The spot-market based system without any intermittent demand; the same but now with a substantial portion of intermittent capacity; and the two-market design with a group of flexible customers.

The first two spot-market cases demonstrate the impacts of the intermittent renewables have on the spot market, a design that was created before the variable renewables formed a relevant generation option. The third case, the two-market design, demonstrates one possible response to the intermittent challenge by creating a lower priced product with restricted availability. It also creates a structure in which it is possible to operate without economic support.

Simulation is carried out using a representative day, i.e., 24 one-hour time steps. We define two kinds of simulation runs based on consumer response. In the first it is assumed that consumers do not react at all to changing supply conditions. In the second simulation consumers adapt to variable supply in two possible ways.

One of the main requirement for a sound electricity market design is that it creates an efficient and sustainable structure: the product prices are as low as possible but at the same time all the generators that are needed in meeting the demand are able to cover also their capital costs. Sustainability of the alternative structures is studied by comparing the levelised unit fixed costs of energy generation and short-term unit net revenues for each of the plants. Zero or positive result indicates sustainable operation.

4.5.1 Input values

Input data consists of definitions on supply, demand and operational features. The last mentioned issues are explained focusing the actual case at hand.

Table 3. Power plant data for the simulation.

Power plant	Fuel type	Capacity MW	Efficiency	Capital cost EUR/kW	Fixed O&M cost EUR/kW,a	Variable O&M cost EUR/MWh	Capacity factor	Lifetime years
Sellingport	Coal	1000	0.4	1000	3.3	1.2	0.85	40
Atcombe	Gas	500	0.55	550	1.2	3.5	0.9	30
Raccoon Valley	Coal	500	0.42	900	3.3	1.2	0.8	40
Amblington	Oil	3000	0.5	350	1.5	2.5	0.8	40
Aquehanna	Gas	1500	0.6	850	1.2	3.5	0.9	40
Langville	Coal	1800	0.45	800	1.3	1.2	0.5	40
New Worthing	Oil	2000	0.55	400	1.5	2.5	0.9	30
Seres A	Wind	3200	1	1000	5	2	1	30
Seres B	Nuclear	1000	0.35	2200	5.5	3.6	0.85	35
Odessa Hills	Wind	1600	1	1200	5	2	1	30
Casa Serena	Nuclear	1200	0.4	3000	5.4	3.6	0.85	30
Alcota Pass	Wind	2400	1	1400	5	2	1	30
Los Gatitos	Biomass	800	0.45	1100	3.1	4.1	0.85	30

This is stylised data on power plants. It does not represent any existing plant but gies a fleet of plants with alternative features.

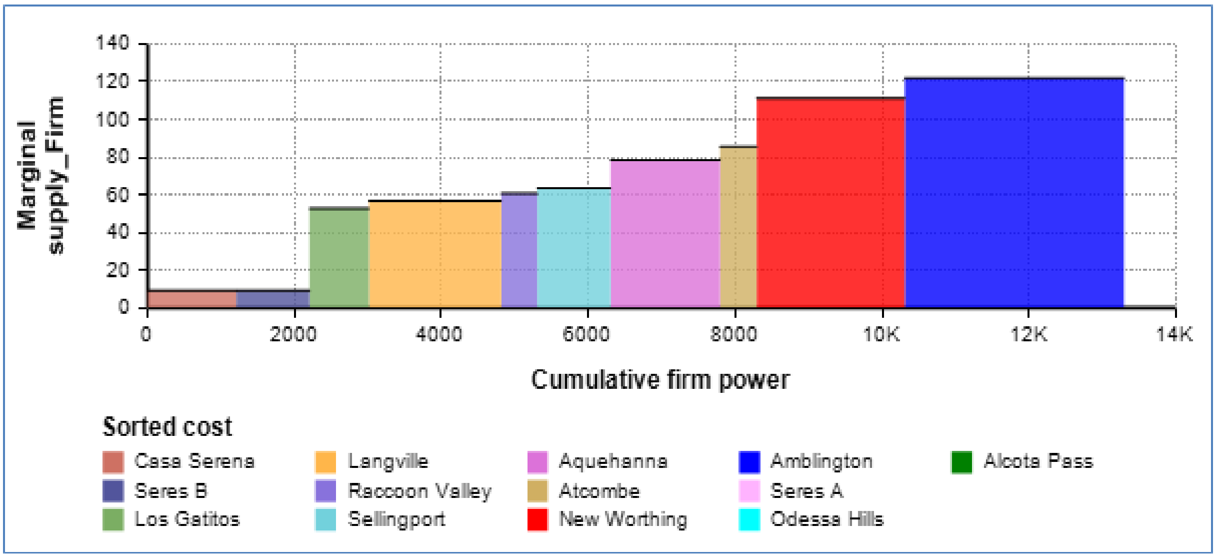

Figure 5. Supply of firm and flexible plants.

The data in Table 3 shown as a supply curve but without the mentioned wind power parks. Variable renewables (VRE) cannot be shown in the supply curve like the flexible generation forms. Their aggregated supply during a day is shown below.

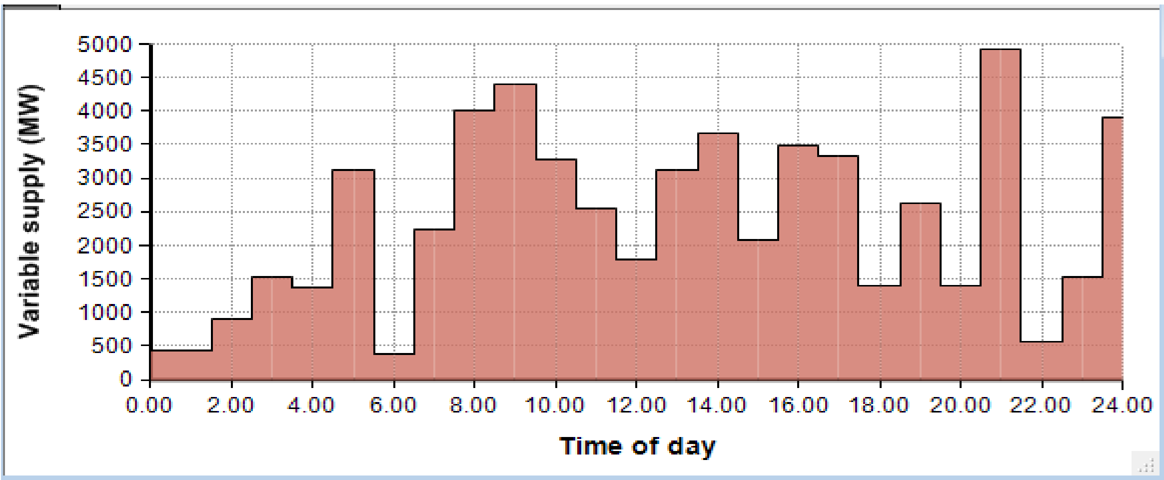

Figure 6. Non-firm supply.

The variability of supply shown in figure 6 is randomly generated synthetic data. Real wind power generation variability may differ from this but the main point here is to use some non-dispatchable supply. In reality there may be several sources for energy in this second energy market merged into one supply and in this way its realisation can be similar to random walk.

Demand in its original form is defined as time-dependent function, Figure 7.

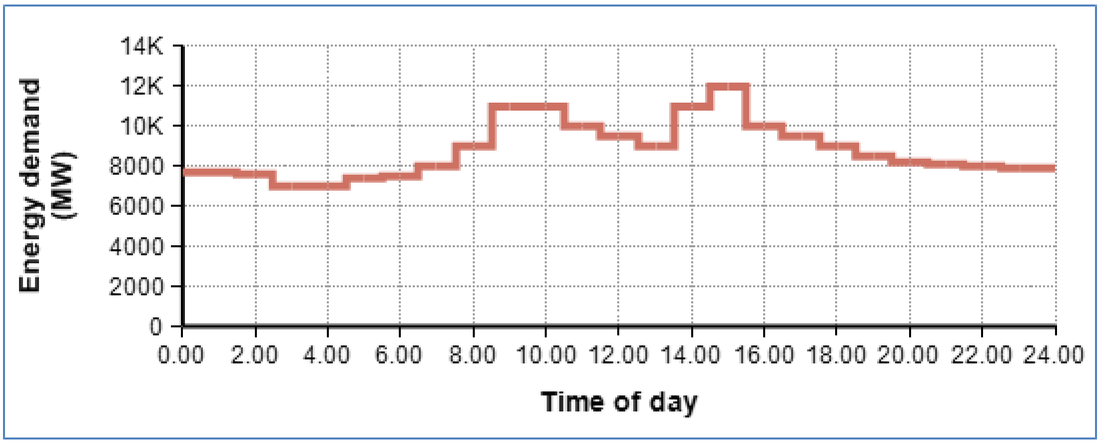

Figure 7. Original demand.

Power system analysis focused on finding out the impacts of variable generation usually replaces the demand with residual demand. It is obtained by subtracting variable generation from the original demand. Residual demand is the demand that must be met by flexible or firm generation forms. Another factor affecting the original demand is the changes the customers are making in optimizing, i.e. minimizing costs with regard to their electricity use. Three alternative assumptions will be made on this below.

4.5.2 Results

4.5.2.1 Impacts of VRE generation on plant economics

First it is demonstrated how the large share of VRE generation affects the plant economics in a spot-market structure. This is carried out by comparing two model runs. In the first run only firm generation capacity is used to meet the demand. In the second run, the above described intermittent zero marginal cost supply technologies are added to the generation fleet.

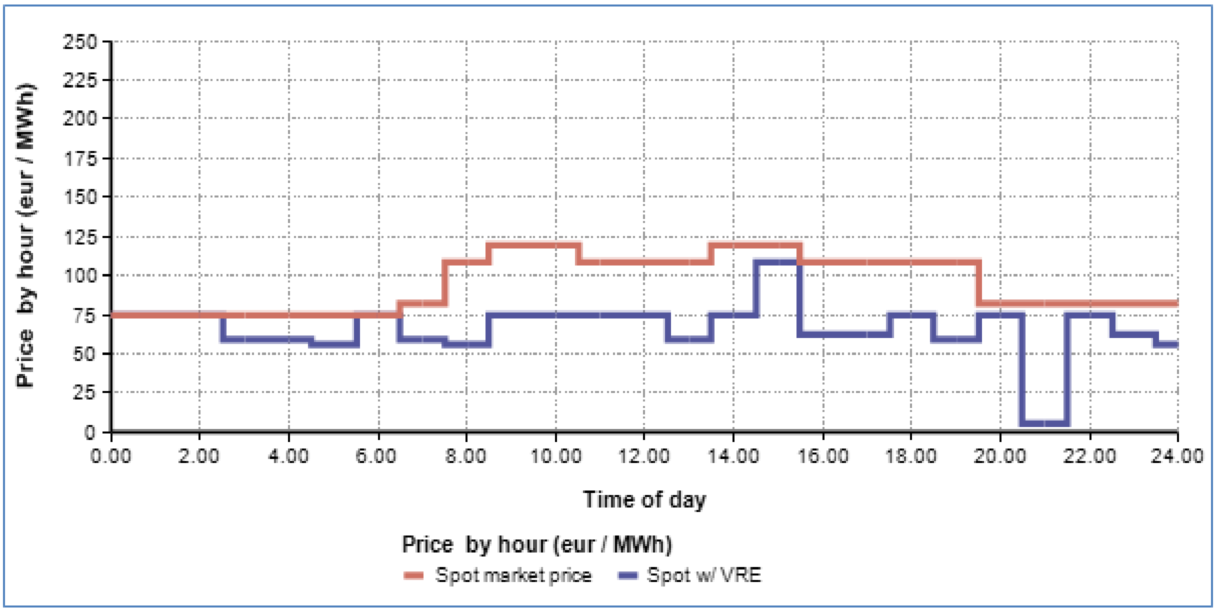

Figure 8. Prices is spot-market without VRE technologies and with them (w/ VRE).

The impact of VRE technologies is clearly seen: they bring the prices down. These prices are based on the power supply of the flexible plants. Their output is shown in
Figure 9 below.

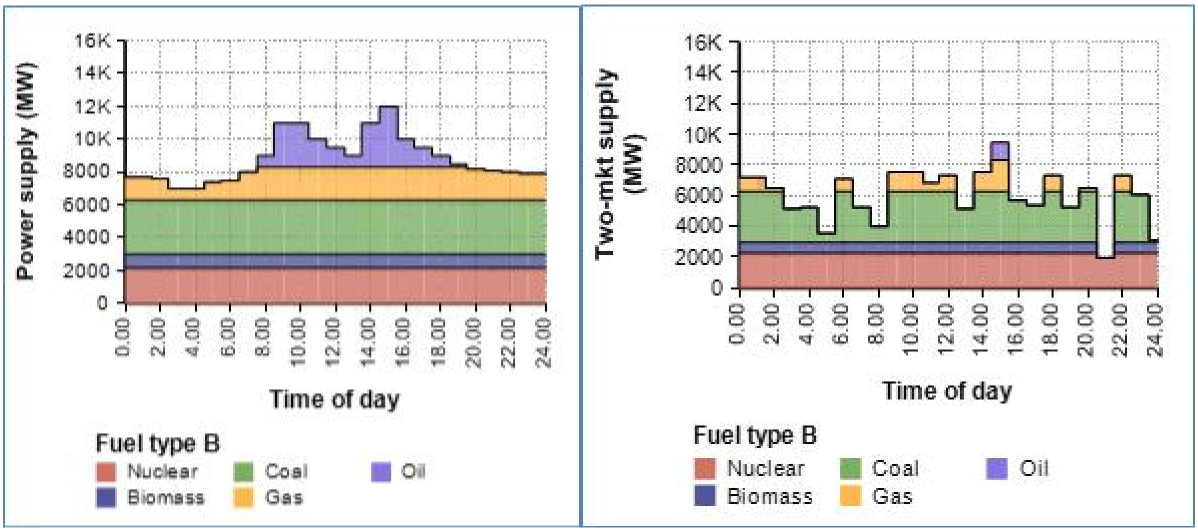

Figure 9. Spot supply without the VRE technologies (left) and with them (right).

Figure 9 shows how the flexible plants generate in meeting the residual demand. That is why variable generation is non-existent in the figure: It has already been subtracted from the original demand.

The variable generation coincides amazingly well with demand as it seems to has shaved almost all the peaks of the residual demand curve. It is only an outcome of randomly generated time series. with different VRE generation profile the results may have been quite different.

Nevertheless, we shall continue to analyse the results based on this form of variability.
Figure 10 shows the short-term rents in an hour when the market price of electricity is 157 eur/MWh.

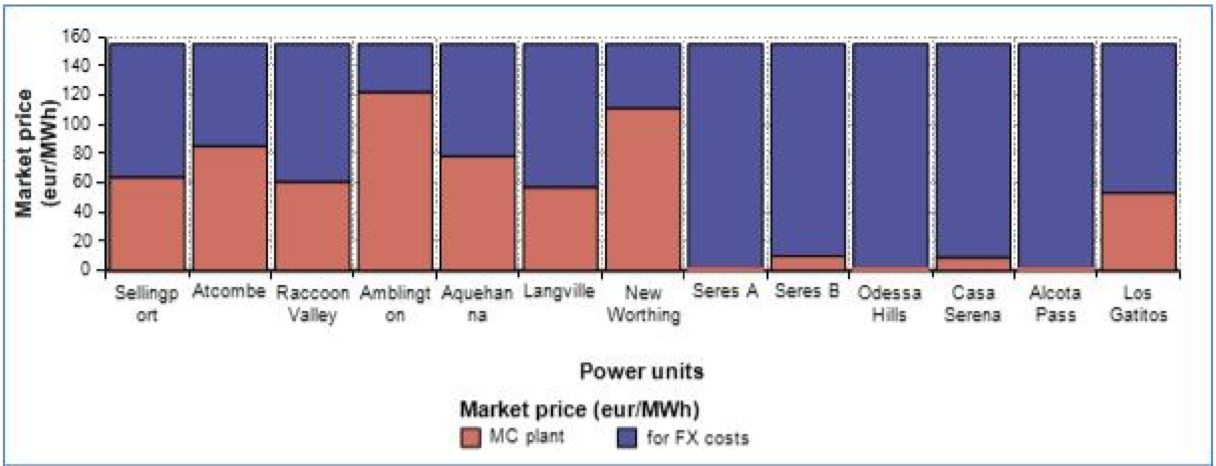

*Figure 10. Short-term net revenue (*for FX costs*) for covering investment costs.*

The blue area describes the marginal surplus that can be used to cover investment costs. This surplus is defined for each hour, summed over the representative day and then divided by the energy generated. This is done for each plant individually. The figure obtained is the revenue per each MWh generated. The yearly unit investment and fixed operation and maintenance costs are divided by the yearly energy generation to obtain the yearly unit fixed costs. The yearly unit cost are subtracted from the yearly unit revenues and the results are presented in figure 11.

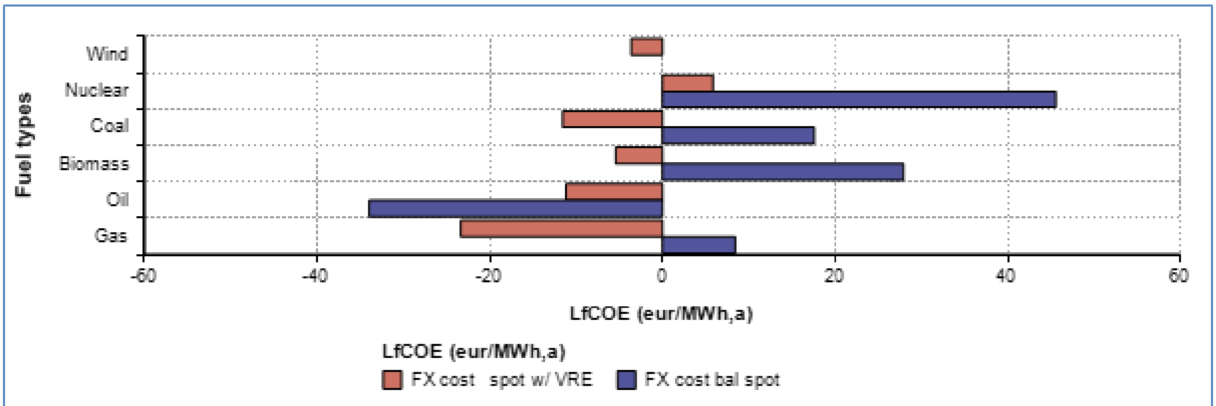

Figure 11. Plant economics as a balance between levelised costs and revenues on capacity.

The effect of including VRE technologies into the spot-market (brown bars) is clearly seen in the deteriorated plant economics when compared to the situation without VRE supply (blue bars). Not even the VRE technologies themselves are able to operate sustainably. Only nuclear plants show positive result.

The situation without the VRE supply is different. This is situation the spot-market institution was designed for. Only the marginal plants, oil-fired gas turbines, have negative economic situation. In the ideal situation these plants get remunerated during those rare occasions when supply is tight and the price rises very high. The used representative demand curve do not reveal this occasions, so it is natural that these plants show negative outcome in these circumstances.
The comparison above is not quite fair for the VRE case. This is because the structure of the firm power fleet is the same in both cases. It describes the present situation characterized by a very rapid construction of the variable capacity. As times pass the structure of the generation adapts to the new situation and that would improve the situation.

The next chapters study the impacts the two-market approach brings to this problem.

4.5.2.2 Two-market case with customer flexibility

The problem with VRE technologies in the spot-market environment is that they bring the price of electricity down making the overall situation unsustainable for all plant types. Without these zero-marginal cost technologies the spot market functions as planned with only some uncertainty about the economics of the marginal plants: can they be remunerated without some additional structures? The two-market design tries to solve the VRE-created problem by acknowledging the characteristics of the VRE technologies by adding a separate market and additional product. This design incentivizes consumers to be flexible and lets the spot market to operate the way it was originally planned.

The simplest possible way to describe a flexible customer group is to modify the incoming intermittent supply into static decrease in power demand. The next figure shows how large a static demand decrease, as a share of the original peak demand, is applied in the simulation, Figure 12.

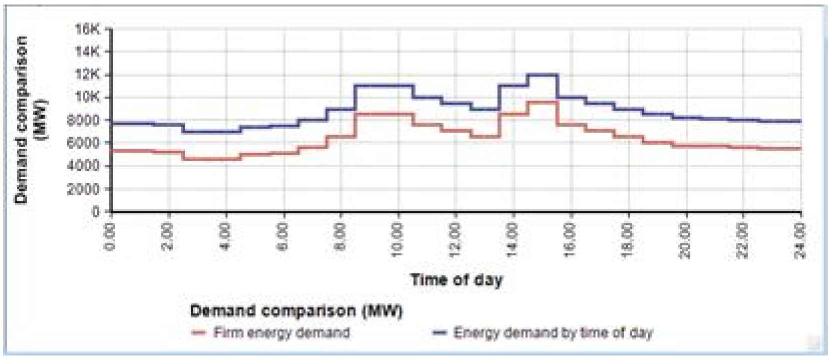

Figure 12. Original and residual demand.

In every hour the demand is decreased with the same amount. This decreased demand is naturally reflected in the supply demand, Figure 13

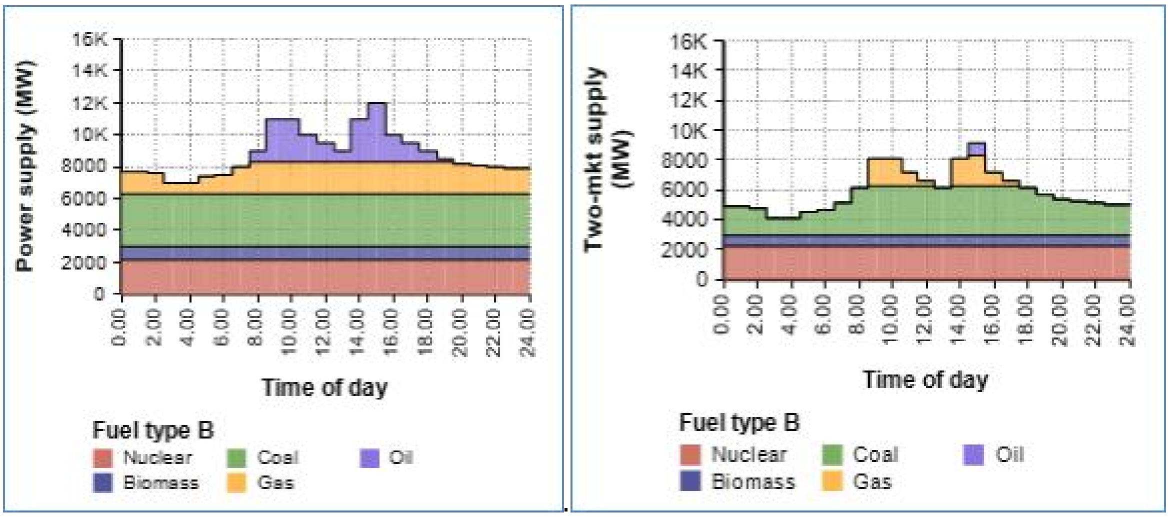

Figure 13. Power supply in the spot-market without the VRE supply (left) and in the firm-power market (right) with the VRE supply.

When consumer flexibility is assumed to be “static“, the residual demand met in the firm market has the same variability as in the base case. Only the level of the demand is lower. The difference is clear when compared the right panel of Figure 9 with the right panel of Figure 13 above.

The simple simulation models in use is not able to differentiate the supply situations in right panels of Figure 9 and Figure 13 due to the fact that it calculates only energy based costs in a static way. There are neither dynamic control restrictions nor increased cost due to starts and stops of plants or ramping them quickly up or down. These are substantial cost sources in real operation.

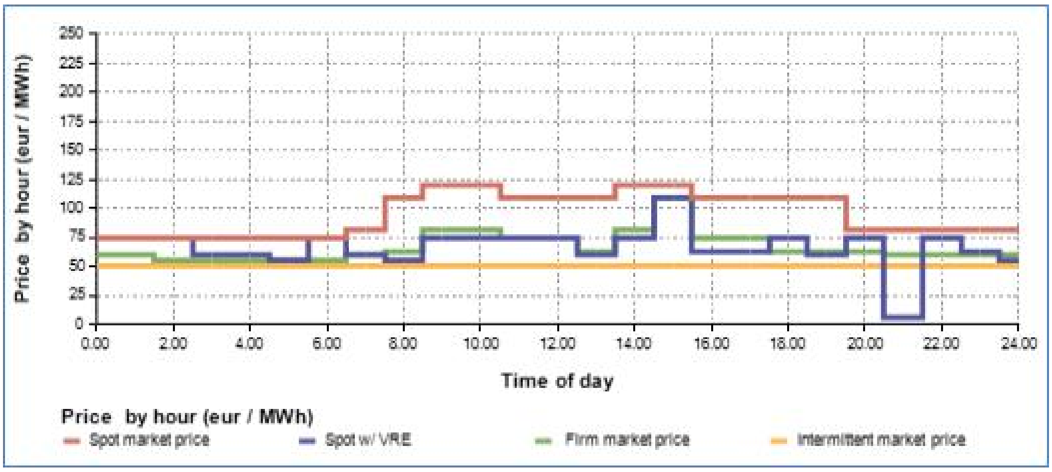

Figure 14. Spot/firm-market prices. The two-market cases are added on price curves in Figure 9.

The product of the intermittent market energy stays on the lowest level in all but one hour incentivising its use. In the future it is expected that the costs will come down due to the technology development making it even more attractive product.

Customer flexibility is the cause for the fact that the average supply of the firm power market is on a lower level than in the original spot-market case. In the simulation the firm market capacity has not adapted to this but is on the original level. This explains the lower market price compared to the original spot-market price. Had the capacity been optimized to reflect the changed demand situation, the price level would have been the same as in the original spot-market case due to the same variations in demand.

There are only minor differences in the prices in the original spot-market with VRE supply compared to the firm-market prices in the two-market design although the supply situation is quite different.

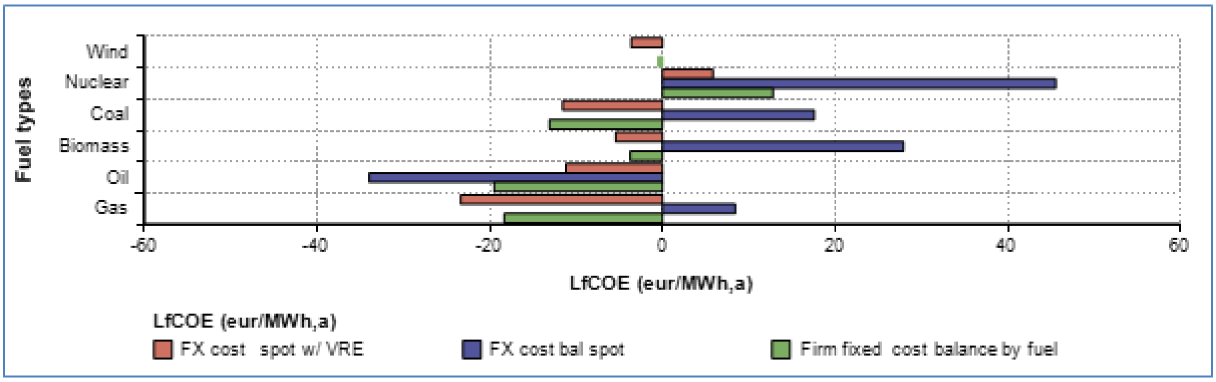

Figure 15. Fixed cost recovery classified by plant fuel.

After capacity adaptation, the economics of the firm power market is the same as in the original spot market due to the same overall structure of the demand. The only difference would be the level of demand. Due to the larger variability of the residual demand it may assumed that without demand flexibility the spot market variability would be higher and the costs to meet it would be higher. This is, however, left for future projects.

4.5.2.3 Two-market case with refined flexibility

To find out the impacts of customer flexibility on supply economics another flexibility pattern was defined. In this time flexibility changes residual energy demand in a more focused way, Figure 16.

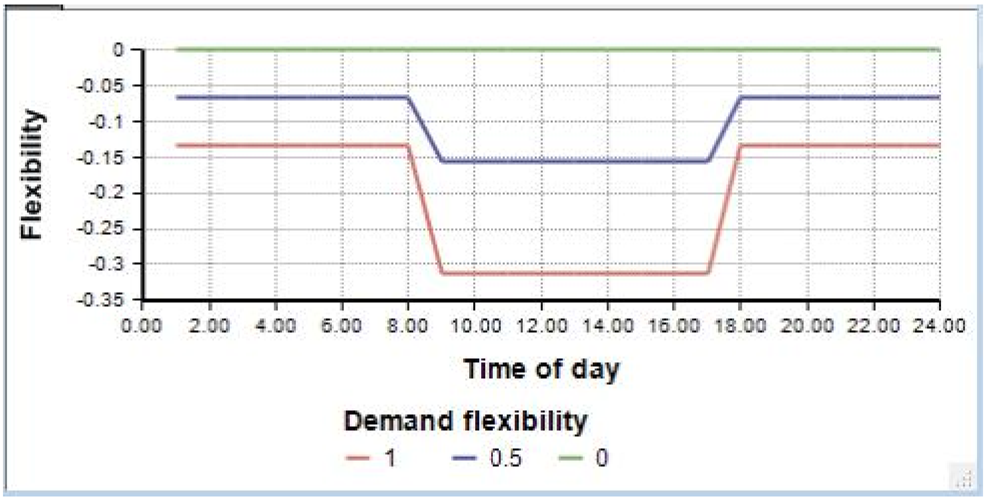

Figure 16. Changes in demand due to flexibility as a share of maximum demand.

The changes are largest in the middle of the day when the demand is at its highest. The absolute changes are shown in the Figure 17.

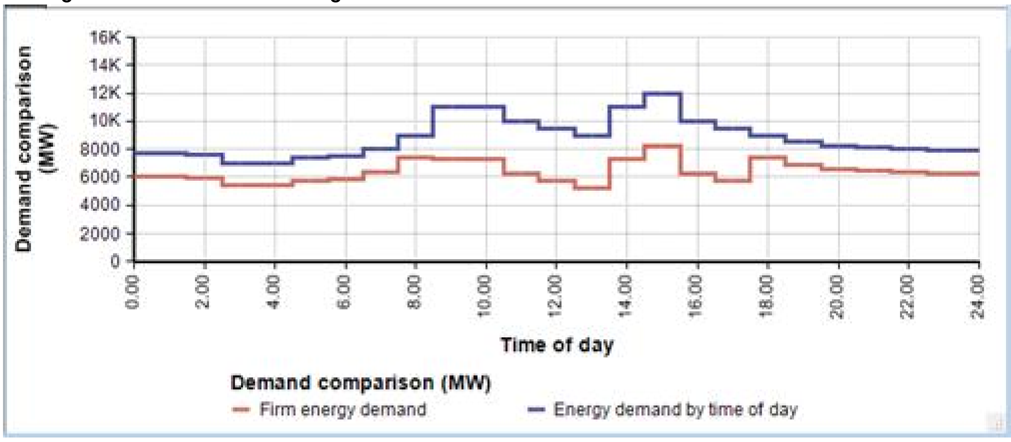

Figure 17. Original demand and residual demand in firm-power market.

Compared to the original demand, the residual demand is looks now more like variations around the daily average than a two-peak daily duration curve. The supply-side adapts to this accordingly, Figure 18.

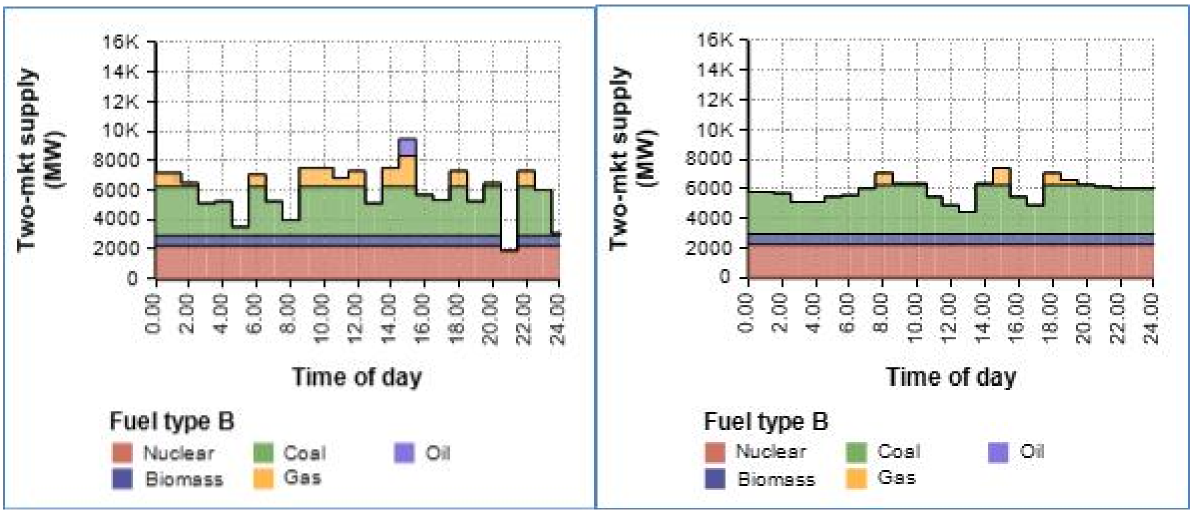

Figure 18. Spot-market supply without customer flexibility (left) and firm-market supply with refined flexibility (right).

The firm-market faces residual load on the right. It has a lot easier profile to be followed than the corresponding spot-market based case on the left. And again, the simulation model cannot yet price these dynamic features. That is why the price figure below shows the same kind of dynamic features for both of the cases.

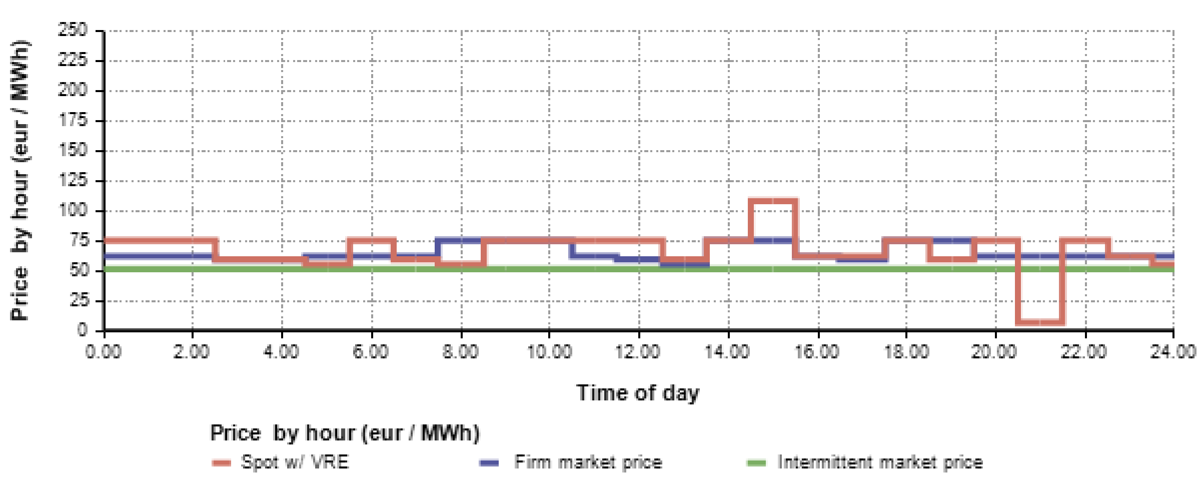

Figure 19. Prices when flexibility focuses on the peaking period. Spot w/ VRE means spot-market with VRE technologies included.

The small step at 15 o'clock in the spot-market is due to the fact that the oil-fired plants generates during that hour. Similar hour-based curves translate to similar overall plant economics, Figure 20.

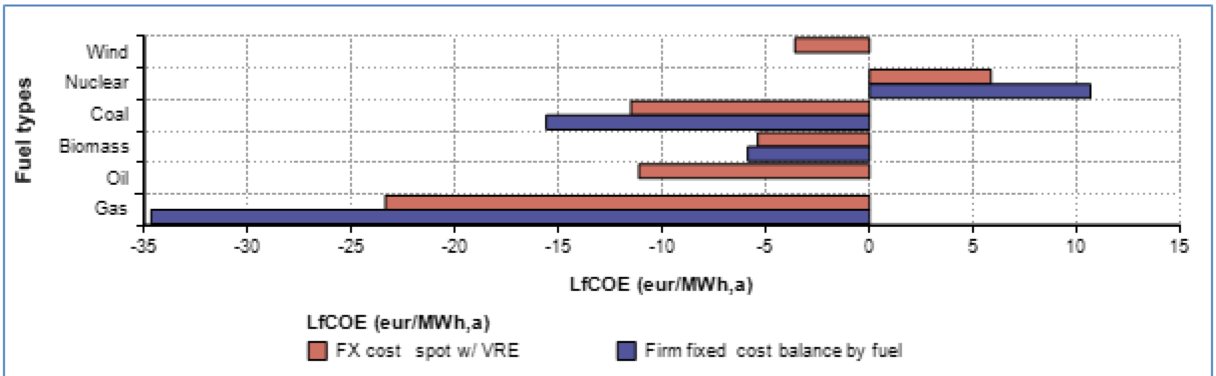

Figure 20. Only nuclear seems to be sustainable in this case. The differences are small among the two designs.

The two designs are almost similar in economic respect although the supply situation makes one to expect otherwise. The explanation is here the as before: non-optimized capacity and the neglect of dynamic features in plant commitment and generation.

4.5.3 Discussion

Spot market design works fine in the circumstances of the last millennium when the zero-marginal cost renewables were not an option in large-scale power generation but power supply was based on the firm and flexible dispatchable generation technologies. The main uncertainty and unresolved issue of the design was the cost coverage of the marginal plant, the so called missing money problematic.

Zero-marginal cost technologies have changed the power-market game: their penetration to the market has been based on the ample economic support they have enjoyed everywhere. The original spot-market design with economically supported zero-marginal generators lead to low average power price, so low that it makes the system unsustainable. But these variable renewables are indispensable in decarbonising the power system. To make the spot-market to survive its structures need to be updated so that the generators regain economic sustainability by being able to cover their investment cost by market-based prices.

The two-market design is an attempt to correct the shortcomings of the basic spot-market design by acknowledging the characteristics of the non-dispatchable zero-marginal technologies. It aims to ensure the healthy operation of both the firm and flexible generation and variable renewable technologies. The crucial feature in the two-market design is the creation of a separate market for the variable zero-marginal cost technologies because zero-marginal cost cannot be used in short-term price formation – zero-marginal cost leads to a fixed price world. It is a capacity, not energy, market. This generator separation makes it possible to offer a low-cost variable product to customers. This incentivizes flexibility in demand on an everyday basis making demand-side investments in flexibility a viable option.

The simulations carried out thus far indicated that the two-market model has features sought for, but the model is currently too simple to reveal them in a rigorous enough way. More work is needed here. But the starting point is intriguing and well worth more detailed study.

5. Separate renewables market in NordPool environment

This section deals with the problem of how could a separate renewables market be implemented without disrupting current market structures.

Here we present a thought experiment of how a separate intermittent renewable market, basically a wind power market in the Nordic system, could be made to work using mainly the tools we have already today. The basis for this alternative is to split the markets with a firewall and have a Wind System Operator (WSO) managing the wind market, see Figure 21.

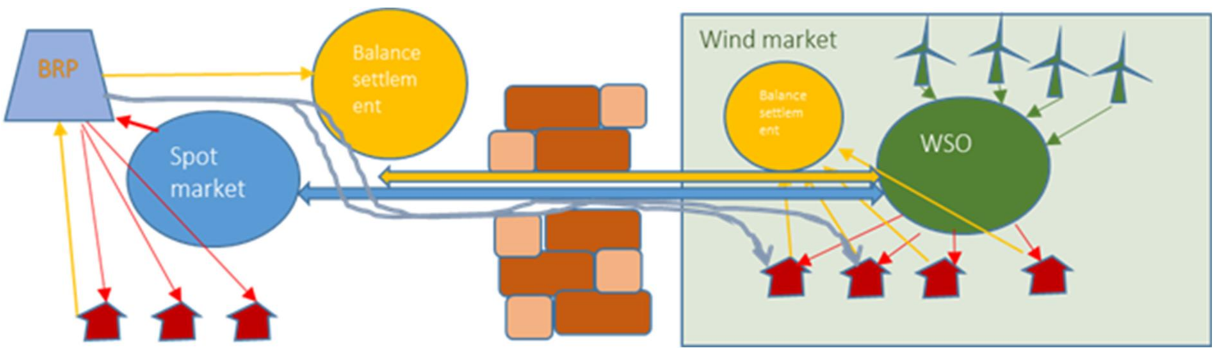

Figure 21. Schematic overview of the two-market model using the tools of today. Yellow arrows = imbalance settlement, red = purchased market electricity (pro-rata in the wind market), grey-blue = fixed deliveries, blue spot market participation, green = wind power deliveries.

The WSO has the system balance responsibility for the wind power generators and the end-users using the produced wind power. Contrary to the “normal market”, here the consumption is supposed to follow the generation. The price tariff in the wind system would be constant for all load that follows the generation, and bear a high price for load that do not follow the generation, i.e. the end-user would be individually balance responsible. The price level would be lower than in the normal market to attract users, see Figure 22, and decided by the WSO, at least in the beginning. With price-guarantee tariffs for the wind producer in existence, the guarantor, i.e. the state, is expected to pay a difference anyway. Market mechanisms such as auctions might be used later. If the end-user flexes his load to match the production, see Figure 23, he will only pay the WSO base wind price, if not, the extra balancing costs will raise his average costs above the normal market price.

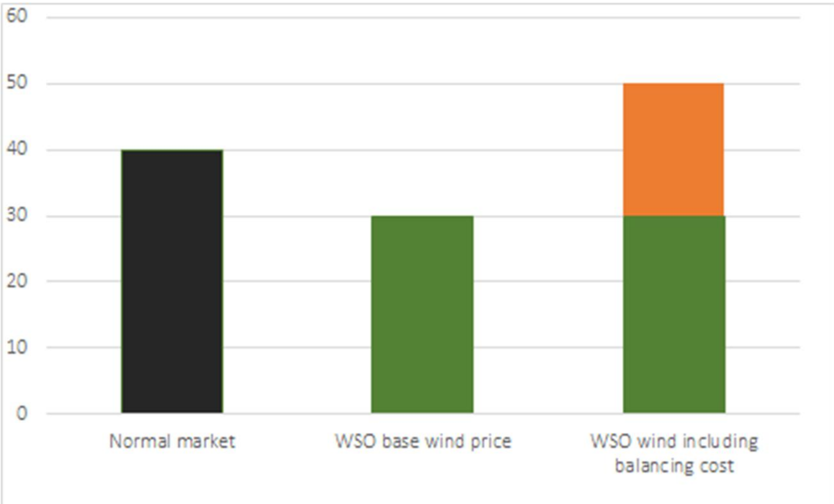

Figure 22. The relative target price levels for the buyer of wind energy compared to buying from the normal market.

The production would be variable and the end-user would get his pro rata share. Imbalances would be paid by the user. The imbalance costs wouldn’t be imbedded in the end-user tariff as they are in the normal market, but paid for separately, see Figure 23. So if we have a windy day and the end-users share is forecasted to be x kW, if he uses less or more than his forecasted share he has to either buy down-regulation or up-regulation at wind balance market price.

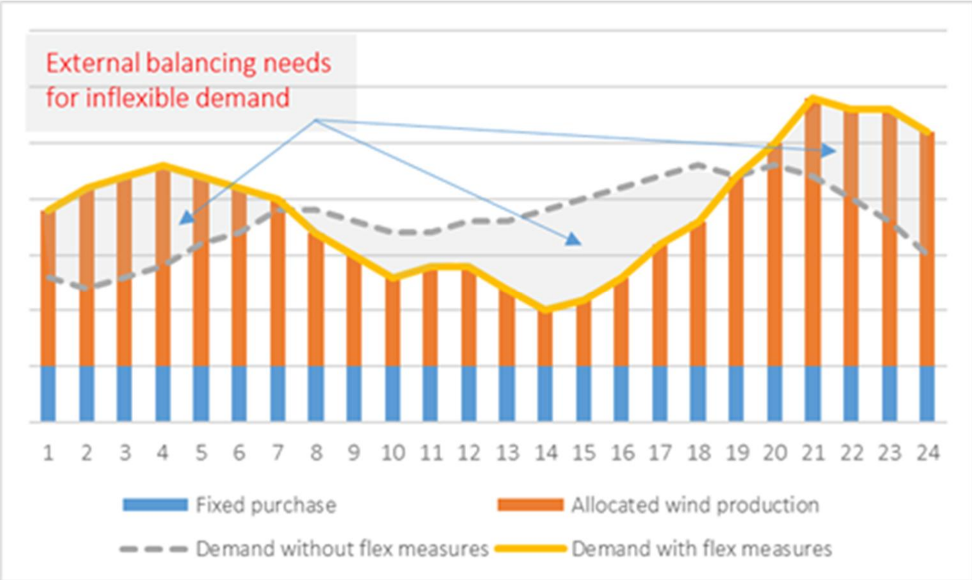

Figure 23. Example of the loads and purchases of an end-user buying a part from the wind market. If the end-user can flex his load, his imbalance costs are zero, otherwise he has to buy or sell energy (grey areas) from the wind balance market.

Table 4 illustrates functioning of the considered market system from two different end-user cases in a given hour. In the case 1, the end-user has a contracted volume lower (5+3=8) than his actual use (9), whereas in case 2, the situation is the opposite. In the illustrative example, the renewables market price is set lower (20) to that of normal market (30), as is considered in the system. In case 1, the end-user has to pay the up-regulation price, which are set as being always less profitable than if the realised volume would have been identical to that of purchased. Similarly, in case 2, receiving the low down-regulation price implies a loss compared to a situation with 8 units bought at 3*20+5*30=210, leading to average price of 26.35.

Table 4. Illustrative example of end-user's volumes and prices in the considered two-market system consisting of normal market and renewables market.

	Contracted from normal market	**Contracted from renewables market**	**Actual use**	**Volume purchased from WSO**	**Total purchase price and volumes**	**Average price/unit**
End-user case 1	5 (units)	3	9	1 at price up	=5*30+3*20+1*40= 250, 9 units	27.8
End-user case 2	5 (units)	3	7	-1 at price down	=5*30+3*20-1*10=200, 7 units	28.6
Prices						
Price/unit	30	20		40 (up) 10 (down)		

Compared to the situation today, the considered market system brings an additional incentive for end-user to flexible operation but also a possibility to enjoy low prices, when available. This is different than today, as the balancing cost of renewable power are more or less divided between all the users of network. In the considered system, the costs and benefits would be more sharply allocated to those responsible of solving the unbalances. The balancing costs would be managed by the WSO. What is important, the system could be implemented without major renovations on metering systems.

The wind energy producer in turn would be responsible for imbalances between forecasted and actual production. The WSO can estimate from experience his own imbalance, that is, the difference between produced and used wind power, and can sell surplus wind production and buy additional power in the normal spot market. To not disturb the normal spot price mechanism, these WSO offers would be calculated after the spot market system and area prices have been settled. If the WSO needs more energy, then costlier supply offers will be met and paid by the WSO. If the WSO sells surplus wind, other production will be replaced and the WSO gets what the new spot price would be. Here the additional revenues in the spot market could, for example, go to the replaced production and to some kind of marginal capacity fixed cost fund.

The normal system operator (SO) manages the balance market. The balance settlement would allocate imbalance costs to the WSO with an own price setting:

1. if the WSO side was overproducing and there was down-regulation, they will get the down-regulation price.
2. if the WSO side was overproducing and there was up-regulation, they will get the lower of the WSO spot price and the normal spot price.

3. if the WSO side was underproducing and there was down-regulation, they will pay the higher of the WSO spot price and the normal spot price.
4. if the WSO side was underproducing and there was up-regulation, they will pay the up-regulation price.

The extra balancing revenues the SO receives, compared to normal side actors, can again be funded for capacity repayment use or, for example, to reduce the balancing fees of the normal side. The balancing costs could also be recalculated subtracting the WSO share first either as such or in some kind of pro-rata share.

Overall, the point would be that the WSO end-user price would be lower than the normal price, if the consumption follows the given forecasted share of wind production, but clearly higher, if no demand response would be taken. As it is possible to have both a fixed and an open part of one's delivery, a WSO client could still buy a beforehand agreed on fixed part from the normal side. The fixed purchase could be a constant load or could follow a predetermined weekly load.

As not all consumption would have to be purchased from the WSO, a lot of environmentally friendly end-users could buy at least a share of their load therefrom. And households with electric heating and storage could buy that part of their need from the WSO. In the beginning, wind producers receiving support would be forced to be part of the WSO system. And afterhand, there could be two-sided auctions with both users and producers partaking.

The normal side would have less spot price disruption from the insertion of renewables to the power system, and the WSO side would pay more for the imbalances. This would be a purely fiscal solution with minimal impact on the computer programs and data management needs in use today. It would be a great incentive for demand response, and it might also be a good meter for the amount of new wind (and PV?) capacity the market is ready to absorb.

Due to shortened project resources, no actual model calculations were made to determine the feasibility and money flows in a system like this. Neither are all money flow channels or alternatives expressed here. The main point of interest is that the spot price would be more stable than in today's mixed market, active end-users would have strong incentives to regulate their use according to varying wind (and PV?) production, and the wind market participants would take a strong responsibility of wind imbalance costs. All would benefit, and the excess social welfare would stem from the increased use of end-user flexibility. As an afterthought, with future levelised costs of electricity of wind and solar showing promises of being low compared to many other production forms, a two-market system like this might work even without subsidies for wind production.

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Appendix: Q&A

Questions[4]:
What is wrong with the current electricity market?

Claim	Clarification/consequence
"Market prices are too low"	Due to subsidized capacities with low variable costs, market prices fall. Eventually, the price level is artificially fallen beyond a level of short-run marginal costs. This causes generators making losses and capacities exiting the market. This leads to vicious circle of only subsidized capacity surviving in markets. Consequently, efficiency benefits initially justifying liberalized markets are lost.
"Market prices are too high."	This is due to market power in electricity markets showing characteristics of oligopoly markets. The oligopolistic operation results in inefficient system from economy point of view. The problem is at it extreme during the system stress hours. This is due to nature of inflexible electricity demand. It causes inability of demand-side to respond the high prices. Generators enjoy windfall profits. This problem is emphasized in electricity markets that have many barriers in market entry.
"Markets do not produce enough flexibility" "(or lack an essential quality of considering techno-economic phenomenon X)"	The inability of markets to not tackle flexibility causes the system to collapse or at least develop in inefficient way.
"Markets do not produce enough capacity"	Due to oligopolistic nature of the market and barriers in entry, the producers' operation leads to insufficient capacity from societal point of view.

[4] This report was prepared in a series of internal meetings by the authors. In these meetings, a series of claims often presented on electricity markets was used to outline the work.

What proves the claims in (1)?

Claim	Suggested arguments	Suggested counter-arguments
"Market prices are too low"	a. SRMC not covered b. LRMC not covered	The market works as it is supposed to work. Low prices are normal phenomenon and they signal of overcapacity in the market
"Market prices are too high."	a. The power producers make extraordinary profits. b. Analysis of HHI etc. c. Simulations (Game-theoretic, competition models (Cournot etc.))	a. The market works as it is supposed to work. High prices are normal phenomenon and they signal of capacity deficit. b. These profits are not extraordinary and they are resulted from power producers right strategic choices
"Markets do not produce enough capacity"	a. The power producers make extraordinary profits. b. Capacity sufficiency seen threatened based on simulations	Relying on markets leads to optimal amount of capacity. Suggested lacks in capacity sufficiency are tackled by markets, however, with inertia in capacity expansion and this is also a normal phenomenon. The problem is primarily caused feed-in tariff schemes having a dampening effect on prices.
"Markets do not produce enough flexibility " "(or lack an essential quality of considering techno-economic phenomenon X)"	a. Simulations of extreme cases. b. Analysis by system operators/regulators	a. One should not interfere with the markets. The market mechanism produces enough flexibility in the market. b. Flexibility characteristics should be left under the responsibility of System Operator who uses appropriate tailor-made market mechanisms.

What are the discussed solutions?

Claim	Solutions suggested
“Market prices are too low”	a. Capacity mechanisms to tackle the missing money problem – several approaches as described in SGEM reports (Koreneff et al. 2014 & 2015) b. Leave it for market to judge, it’ll lead to optimal, “right” prices
“Markets do not produce enough flexibility	a. Increase flexible components in market systems ● 15-minute markets (or even shorter) ● Pool with centralized optimization of flexibility resources b. Install flexible technology c. “2-market solutions” d. “Platform markets”
“Market prices are too high.”	a. Making market entry easier b. Anti-monopoly measures c. Stricter regulation of the market d. Increase demand side flexibility to avoid vulnerability to market power
“Markets do not produce enough capacity”	a. Capacity mechanisms – several approaches as described in SGEM report (Koreneff et al. 2014 & 2015) b. Leave it for market to judge, it’ll lead to optimal mix of capacity.

Is there anything especial/new regarding FLEXe environment? Or is a solution something discussed even for decades?

Claim	Solution	FLEXe related novelty/research question
"Market prices are too low"	a. Capacity mechanisms – several approaches as described in SGEM reports (Koreneff et al. 2014 & 2015) a. Leave it for market to judge, it'll lead to optimal, "right" prices	How the capacity mechanisms considers - Quality of capacity? - Opportunities of new technology utilized?
"Markets do not produce enough flexibility	a. Increase flexible components in market systems b. 15-minute markets (or even shorter) c. Pool with centralized optimization of flexibility resources d. Install flexible technology e. "2-market solutions" f. "Platform markets"	Do the market system alterations suggested consider options and impacts brought by technology, esp. demand side? Does the market system alteration has a special target on incentivizing small-scale players?
"Market prices are too high."	a. Making market entry easier b. Anti-monopoly measures c. Stricter regulation of the market d. Increase demand side flexibility to avoid vulnerability to market power	Introduction of smaller players, prosumers
"Markets do not produce enough capacity"	a. Capacity mechanisms – several approaches as described in SGEM reports (Koreneff et al. 2014 & 2015) b. Leave it for market to judge, it'll lead to optimal mix of capacity	