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ANALYSIS OF DANISH MARKET MODEL

A report to Energistyrelsen

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ANALYSIS OF DANISH MARKET MODEL

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EXECUTIVE SUMMARY

Denmark is part of the Nordic energy market, a successful international energy market that was the basis for the European Target Model. Its design is based on energy-only principles, including decentralised trading and scheduling and the concept of balance responsibility. Denmark is placed between a very large and liquid Continental market and a market with surplus of both energy and flexibility.

The ambition of reducing Danish emissions of greenhouse gases in 2030 to 30% of 1990 levels will require a fast track solution based on electrification of transport and heating. This may however reduce access to flexibility for future system operation, limiting the ability to meet increased volatility in demand and generation in the following timeframes:

1. **Seasonal flexibility**: having enough energy to meet seasonal (usually winter) peaks in residual demand (demand minus expected renewable generation);
2. **Residual peak capacity**: having capacity to meet expected residual peak demand (i.e. demand minus expected renewable generation) in a given time of day;
3. **Within-day adjustments**: sufficient capacity to adjust dispatch based on updated forecasts of demand and renewable generation within day, i.e. between day-ahead market outcomes and the balancing timeframe; and
4. **Real-time flexibility**: (post-gate closure, within 15 minute balancing interval) to support system frequency in response to unforeseen events.

Flexibility must be available in different locations to mitigate grid constraints between price areas, within price areas and (increasingly in future) within distribution networks. In the transition period, the market design must exploit all potential sources of flexibility.

Market design success criteria

Electricity markets in Europe are facing the 'Trilemma', developing a market in balance between decarbonisation, security of supply and economic efficiency. Based on the energy-only principle, electricity markets should focus on price paid per unit of electricity as a signal of scarcity in supply in specific times and places, or for options on such deliveries. Contracting to ensure availability of capacity undermines the energy-only design.

In systems dominated by variable renewables, weather-derived variation in output leads to market outcomes which are much more volatile than in the Nordic system. The Danish market may move in this direction, creating new pricing conditions, particularly at seasonally extreme reservoir levels in Norway and Sweden.

In Market Model 3.0, product definitions must place value where flexibility is scarce, particularly related to:

- **Operational timeframes.** The markets must price the various flexibility resources, considering the needs of different actors including BRPs, TSOs and DSOs, allowing the value to ripple out between trading timeframes and locations without barriers.

- **Investment timeframes.** To support efficient investment decisions, pricing rules must be clear in advance and the products must allow trading, hedging and adequate forecasting.

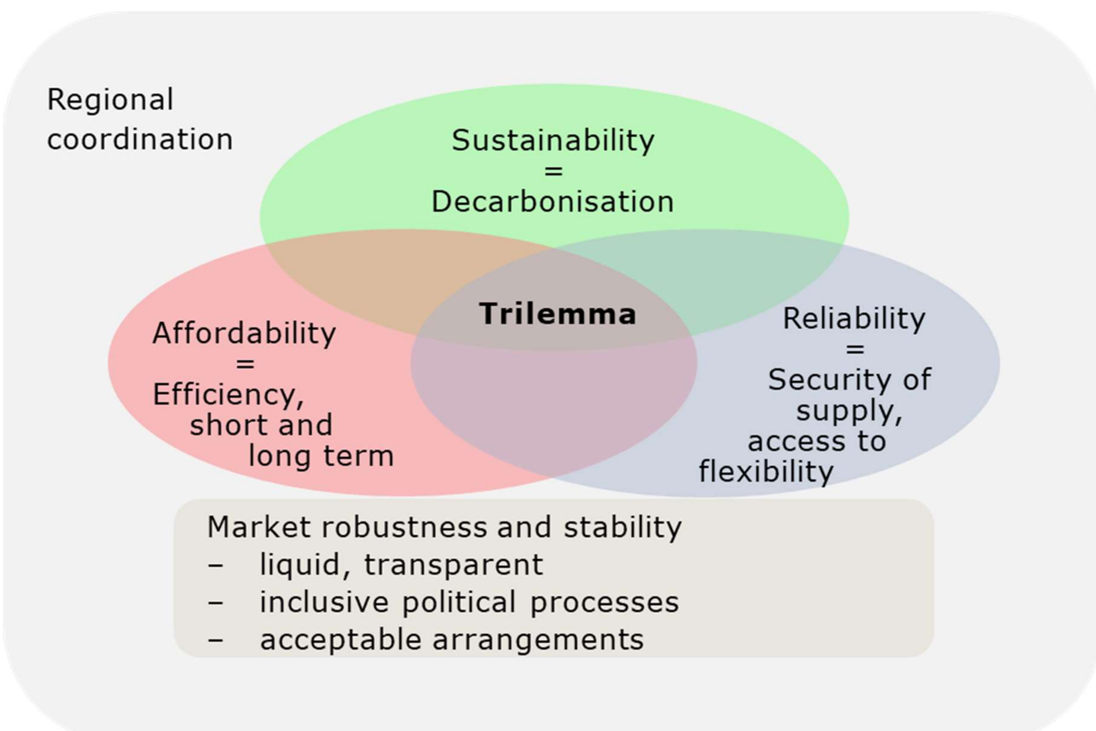
Figure 1 shows how the market design success criteria are linked together.

Market stability: aside from efficiency considerations, the market must be robust, with good liquidity, effective governance and market transparency. Further, enabling the potential of demand to meet flexibility needs will become an increasingly important part of market stability in the future as we move to renewables dominated systems, and as we add new forms of demand which has inherent potential for flexibility.

Political stability: Furthermore, the market must be politically robust, which means striking the right balance between the 'trilemma' of fundamental political objectives developed in a process that minimises the risk of policy revisions.

Regional dimension: Finally, the regional dimension of market design is important. Security of supply is often perceived as a national issue, but in interconnected systems there are regional repercussions. Hence regional coordination and communication (including transparency in advance) around critical situations are needed.

Figure 1 – Market design success factors



Appraisal against market design success criteria

According to Energinet (RFE 2019), the peak capacity situation is at present deemed to be adequate in all timeframes. However, in DK2, the peak capacity in 2030 may not be sufficient to prevent involuntary load shedding in a few hours per year as loads and system needs increase. Following the MM2.0 project, Energinet is setting up pilots to exploit flexibility from EVs, heat pumps, batteries and industry as well as preparing for the establishment of a 300 MW strategic reserve to be made towards 2030 as a last resort.

In traditional energy-only markets, electricity prices are supposed to be the main signal of scarcity and the trigger for generation investment. In future, scarcity needs will take different forms and the pricing arrangements must to some extent be changed to reflect these new complexities. Furthermore, the way in which price zones are defined and how interconnector capacity is calculated and allocated between timeframes will influence what flexibility services have value, where and when.

In most contexts, the Nordic market is energy-constrained and not capacity-constrained. Referencing the four scarcities above, hydropower provides flexibility to cover seasonal energy needs (flexibility 1) and **residual peak capacity** (flexibility 2), whereas capacity to adjust for dispatch errors **within-day** (flexibility 3) and close to **real-time** adjustments (flexibility 4) to a larger extent has to be covered domestically, unless more interconnector capacity is allocated to these timeframes. Both zones of the Danish market are strongly connected under the European day-ahead market coupling, but neither of them is self-contained. A supply shortage in one of them will therefore be part of a more widespread shortage, and Denmark will increasingly be dependent on its neighbours.

Sustainability

The market design should make sure that sustainability (decarbonisation) can be delivered efficiently without jeopardising security of supply. Whereas electrification of transport (smaller vehicles and coastal ferries) may provide important fast, short-term flexibility after 2030, it will increase volatility in the consumption pattern. Electrification of the heating sec-tor will make Denmark more dependent on import for seasonal energy needs, but the heat sector will still be able to provide short-term flexibility by turning off water heating.

Reliability

Reliability, in particular related to flexibility in the timeframes that are closest to operation, providing capacity to correct day-ahead forecast errors and to balance the system will be a concern in a 70% decarbonised world, due to reductions in availability of CHP plants. This will however to a certain extent be compensated by flexibility from the heat sector itself as mentioned in the previous paragraph. The remaining short-term capacity will have to be procured from the market. Intraday liquidity is however weak, mainly due to limited allocation of cross-border transmission capacity, thus straining access to upregulation (generation) capacity from other countries.

Affordability

Affordability for different groups, i.e. the distribution and volatility of costs and prices, particularly in extreme, but rare situations, are in principle market outcomes. With a good market design, they are not economic challenges in their own right, but may present political challenges if they are not properly anticipated. Predefined description of situations and how they are to be managed will reduce the risk of unwanted political intervention.

Transition

The transition phase is as important as the target: ten years is not enough time to develop new technology, and the task will be to reduce greenhouse gas emissions to 30% of 1990 levels using existing technology. There are significant uncertainties which place risks on investors, and there is a need to give as much certainty as possible to limit capital costs. Moreover, infrastructure that can be useful in the future should be preserved, taking account of opportunities related to technology development.

Regional dependence

Denmark depends heavily on other systems in the region. Day-ahead prices and balancing costs are set in a Nordic market, and investments may be needed in a broader region, not necessarily in Denmark. This weakens the incentive to invest in flexibility in Denmark itself, which in turn could be perceived as a political problem: Is the degree of self-sufficiency acceptable and in what circumstances will Denmark have to be fully independent of imports? Working together with the neighbours to solve regional design issues is equally – if not more – important for Denmark as designing their own market.

- Denmark is relying on neighbours to ensure security of supply. Is the degree of self-sufficiency acceptable?
- Are the neighbours happy for Denmark to rely on them, and how reliable are they?
- Is Denmark happy to export its cheap wind for the benefit of its neighbours?

Conclusions

The market design must support investment in new or existing capacity by ensuring good governance, forward-looking transparency and adequate hedging opportunities. Furthermore, the design of the political processes could reduce the likelihood of ad hoc intervention. For the short term, the critical market design issues are:

- provide more cross-zonal transmission capacity to the intraday market;
- review of products and markets in order to provide flexibility across timescales and locations;
- remove obstacles to market pricing, making sure that the ripples of anticipated shortage are allowed to spread across locations and timeframes;

- activate demand side flexibility in the various markets; and
- design new markets that integrate the actions of new groups of active participants in the (near) operational timeframes.

We believe that the electricity sector will deliver most of the decarbonisation needed in the form of renewable generation and electrification, i.e. new electricity demand from other sectors, provided that:

- the vision for the Danish energy system is widely accepted and consistent over time;
- markets provide forward vision to support investment decisions; and
- short-term flexibility is prioritised, coordinated and designed into electrification.

The electricity market has to integrate flexibility for all timeframes in order to reveal economic value and allocate resources effectively as well as prepare for investment decisions:

- accounting for imbalance quantity and balancing price formation in scarcity situations;
- definition of products and future system needs by the TSOs;
- development of protocols for sharing and trading the resources between regions; and
- allocation of network capacity to the various timeframes.

Market-based allocation of cross-zonal transmission capacity between time-frames is critical for a Danish intraday market, but the methodology is not well developed, and would require further analysis. One promising idea to improve the allocation between time frames would be to develop tradeable transmission rights.

Interconnector and transmission network investments needs to follow a well communicated clear decision making process to inform private investment decisions.

1. INTRODUCTION

1.1 Scope/document structure

The consultants Pöyry (now AFRY) and MORE have been appointed by Energistyrelsen to set out considerations for Market Model 3.0 (MM3.0), the electricity market design which will be suitable in the 2030 future in which the Danish Energy system is substantially decarbonised. Previous work by Energistyrelsen and Energinet defining Market Model 2.0 confirmed an intention to use an 'energy-only' model, without resorting to separate payments for (peak) capacity. Our task is not to provide recommendations for MM3.0, but to set the scene for the work and to identify success criteria, to frame the meaning of 'energy-only' in the future Danish context, and to flag potential challenges and barriers.

2. THE SITUATION IN DENMARK

2.1 The situation today

Denmark is part of the Nordic energy market, a successful international energy market that was the basis for the European Target Model. Its design is based on energy-only principles, including decentralised trading and scheduling and the concept of balance responsibility. The eastern part of the country is synchronised to the Nordic area and the western part to the continental area. That places Denmark between a very large and liquid Continental market and a market with surplus of both energy and flexibility.

The Danish electricity sector is complementary to the other Nordic systems. Whereas Norway, Sweden and Finland have an energy-intensive industry structure and a per capita electricity consumption ranking among the highest in the world, Denmark has one of the lowest in the industrialised world, reflecting both the structure and the efficiency in industrial, commercial and household consumption.

The main features of the Danish power market are:

- very high share of wind power (45% total annual demand in normal conditions);
- thermal power generation from highly flexible CHP plants;
- cross-border interconnection capacity that is higher than peak demand; and
- in urban areas, a dense network for distribution of hot and cold water, heated by CHP and an increasing share of electricity.

Denmark's two price areas are usually 'price takers', with power prices mostly set by Nor-way, Sweden and/or Germany. Interconnection is a central part of the system: In 2018, 42% of Danish demand was covered by imports and 36% of its generation was exported, and so far in 2019, Denmark has had a different price than any of the neighbouring areas in less than 8% of the hours.

2.2 The situation in the future

2.2.1 *Ambition*

The Danish government has an ambition by 2030 of reducing emissions of greenhouse gases by 70% (i.e. to 30% of 1990 levels). A new climate legislation was recently announced, presenting these as main targets:

- moving forward the target year for full independence of fossil fuels from 2050 to 2045;
- increasing the 2030 target for reduction in greenhouse gas emissions relative to 1990 from 40% reduction to 70% reduction (on 1990 levels); and
- meeting 100% of the consumption of electricity from renewables by 2030.

Among the instruments, the following have been mentioned:

- five new offshore wind farms totalling around 4 GW by 2030
- stopping sales of new fossil-fuelled cars from 2030, and
- the 2020 finance bill has set aside 65 million DKK to investigate the feasibility of energy islands before 2030 to facilitate 10 GW offshore wind production.

2.2.2 *Electrification*

It is expected that electricity will play a key role in a fast track solution for an emission reduction of 70% by 2030. Several pathways are possible, but it is evident that a green electricity system needs to take some of the heavy lifting of carbon reduction off the shoulders of the transport and heating sectors. Which degree of electrification that is needed and in which sector electrification will prove most cost efficient is not known and needs to be studied.

Electrification is by default the main option for emission reduction in the transition phase until 2030. Emission reductions can also be achieved through the gas infrastructure. However, the technologies for emission neutral gas delivery are either expensive or immature in the short term and strategic choices will have to be made later.

Expected developments are:

- CHP will be further displaced by renewable generation;
- small cars and coastal ferries will be electrified; and
- the heat sector will install more direct heating and large-scale heat pumps[1] as well as domestic heat pumps in rural areas not covered by district heating networks.

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[1] Cf. Frederikshavn Forsyning as well as the demonstration project by HOFOR, CTR and VEKS in Copenhagen.

2.2.3 Flexibility

Due to the decommissioning of CHP which is being replaced by renewables, there are concerns that access to flexibility for future system operation will be inadequate. Flexibility must be available in a number of timeframes to meet volatility in demand and generation for the system to be secure (Detailed description in Sec. 4.2):

1. **Seasonal flexibility**: having enough energy to meet seasonal (usually winter) peaks in residual demand (demand minus expected renewable generation);

2. **Residual peak capacity**: having capacity to meet expected residual peak demand (i.e. demand minus expected renewable generation) in a given time of day;

3. **Within-day adjustments**: sufficient capacity to adjust dispatch based on updated forecasts of demand and renewable generation within day, i.e. between day-ahead market closure and the balancing timeframe; and

4. **Real-time**: (post-gate closure, within the forthcoming 15 minute balancing interval) to support system frequency in response to unforeseen events (potentially including new products including faster frequency response and inertia).

There are different buyers of flexibility by location, and there is an interaction with available grid capacity and the access rights of users[2]. The locational dimension includes:

- (almost location-independent) management of frequency, energy balancing or contingencies;
- transmission grid congestion (whether between or within price zones); and
- distribution level grid congestion (which is anticipated to increase in future as new types of electric supply and demand are linked to low voltage networks).

Although the TSO has a monopoly role in procuring some services today, this may not always be the case. In the Nordic markets, gate closure separates the within-day trading by participants from the flexibility responsibilities of the TSO. This separation is open to review: for example, the Dutch and Belgian TSOs already operate a model of 'passive balancing' in which market participants are expected to respond close to real time to support system balance. In the future, we expect BRPs (Balancing Responsible Parties) to take a more active role in balancing than today. Furthermore, DSOs will procure flexibility to balance the distribution networks from the same market timeframe, and there will be a need for coordination with TSOs both regarding the redispatch decisions and the demand for flexibility. Local marketplaces for

2 Other possible solutions to locational issues can include regulatory measures, including targeted grid tariffs and variations in the level of 'firm' network access.

flexibility are starting to appear, e.g. NODES developed by Agder Energi in Norway.

The various sources of flexibility have different physical properties that make them useful in different circumstances. Fast-responding sources are particularly useful in real-time operation, whereas long endurance resources will be required for the earlier, energy-focused timeframes. Some resources are capable of addressing multiple issues, and a trade-off has to be made between the different uses.

Seasonal energy flexibility and residual peak capacity have traditionally been covered by conventional power plants and imports. As renewables shares rise, peak capacity normally gets scarce and other sources such as demand side flexibility will become increasingly important[3]. Energinet's recent security of supply analysis (Energinet, RFE 2019) shows that capacity adequacy may get strained if decommissioning of CHPs happens faster than expected. This confirms that there will be a need for the market to provide incentives to maintain necessary existing capacity in the market.

Generally, the need for flexibility from sources other than thermal generation will increase:

- Heat may be stored in water reservoirs or in boreholes, and the supply of electricity for heating may be interrupted, thus providing flexibility to the electricity system.
- Battery technology is continuously improving. Scheduling of vehicle charging, and the use of mobile and stationary battery packages may provide flexibility services, but probably only after 2030 at a significant scale.
- Hydrogen can be transported and stored in natural gas storage. Heat from the process can be absorbed by the district heating network, thereby offering flexibility to the energy system, reducing the amount of lost electricity in surplus situations.
- Today, the main part of long-term flexibility is traded on interconnectors. With improved access to transmission capacity, shorter term flexibility may also be traded internationally.
- One of the success criteria for the future market design and the transition period is to harness the potential for new sources of demand to meet future flexibility needs.

2.2.4 Nordic collaboration

The collaboration between the Nordic TSOs has been central to success of the Nordic market. The TSOs are building common IT platforms using services of the 'Fifty IT' company owned by Statnett and Svenska Kraftnät. This will provide more integrated system operation and a common merit order for

[3] This observation may not be relevant for Denmark, since seasonal flexibility generally is provided through interconnectors and the potential for demand response is limited.

balancing services. The Nordic TSOs are developing shared services in operational planning timeframes under the banner of the Regional Security Coordinator (RSC – later to become a Regional Coordination Centre).

The Nordic TSOs have different roles in the market. Statnett and Svenska Kraftnät take responsibility for frequency management in operational timeframes in the entire Nordic synchronous system, whereas there is a shared responsibility for procurement of system services. The TSOs' role in their respective systems is also different. After the review of the Danish Grid Code, the role of Energinet in system operation is separate from its asset ownership roles, whereas the other TSOs have kept their roles as owners and developers. In the future, new levels of cooperation will be required to move the system forward[4].

Nordic collaboration will be even more important for Denmark going forward, as neighbours are also chasing decarbonisation targets. Furthermore, in Sweden there are expectations of closure of the remaining nuclear power stations over the next couple of decades. This will put pressure on the capacity situation in the south-east Nordic region including eastern Denmark.

3. SUCCESS CRITERIA FOR MARKET DESIGN

3.1 Generic success factors

Europe is facing the well-known 'Trilemma' of trying to develop an electricity market that ensures a balance between decarbonisation, security of supply and economic efficiency. Markets must continue to be effective over time and must include mechanisms which ensure stability and fair market outcomes, and which do not invite political intervention.

An energy-only market will have to fulfil the general requirements of any healthy market:

- minimise entry and exit barriers (for generators, suppliers, and in the ability for consumers to interact with the energy markets);
- minimise transaction costs (including cost of operating in the market and balancing portfolios);
- maximise market participants' freedom of choice (including different models for market participation and different appetites for risk);
- provide transparency (in particular price visibility for both end-users and generators); and
- provide predictability of market frames, i.e. reduce regulatory risk.

Market efficiency relies on direct market participation of a reasonable number of independent participants, or in market terms, Balancing Responsible Parties

[4] Cf. Fortum's Energy Review (conducted by Pöyry): From national to regional grid planning https://www.fortum.com/sites/g/files/rkxjap146/files/documents/fortum-energy-review-grid-planning-11-2019.pdf

(BRPs) with their own physical operation, giving diversity and market depth on both buying and selling sides of the markets in different timeframes.

Today's energy system is organised to schedule generation resources to meet the demands of customers. In the renewable-dominated system of the future, generation will be less controllable (whether technically or economically). The efficiency of the future system will depend on capturing the flexibility of demand side participants to meet the capabilities of generation (and networks) over a range of timeframes and locations.

Ideally, there would be a financial hedging market for each of the crucial services, relieving market participants of unwanted risk (for some system services, the TSO could procure, or at least signal procurement needs in advance)[5].

Network access is a thorny topic. Simplistic economics may suggest that prices in each location should reflect surplus or scarcity of grid capacity to serve that location, and that the role of the market arrangements in operational timeframes is to reveal these differentials. However, this would present political and also regulatory challenges: it could lead to prices which systematically vary by location (at a granular level) and which are open to market abuse if certain locations have limited competition.

Further, even if the market arrangements delivered efficient operational outcomes, the inability of participants to make forward hedging contracts based on location would spoil the effectiveness of investment decisions based on locational prices. In practice the resolution of grid constraints must strike a balance between firm and non-firm access rights for grid users, variable or even dynamic grid fees (and loss adjustments) and localised market arrangements.

Ultimately it is the market actors themselves which are providers and users of the various classes of flexibility, and market instruments are needed which explicitly allow these products to be traded between participants in different locations. Transparency is vital, and there will need to be a focus on reducing barriers to entry to permit smaller actors to participate.

The regional dimension of market design is important. Security of supply is often perceived as a national issue, but in interconnected systems there are regional repercussions. Hence regional coordination of long and short term needs as well as communication (including transparency in advance and to the markets) around critical situations are all needed to ensure regional security of supply in an efficient way.

5 In the Danish price zones, hedging is difficult even now. There is no strong local financial market, and the correlation between the area prices and natural hedging instruments like the Stockholm area price, the Nordic system price and the German price are insufficient.

3.2 The theory of energy-only market design

Energy-only electricity markets focus on price per unit of electricity as a signal of scarcity in supply in specific times and places, paying for deliveries of electricity or for options on such deliveries. Paying for general availability of capacity (capacity markets, capacity payments, etc.) and capacity obligations on energy suppliers (certificates etc.) would be outside this definition. Other market designs which – strictly – deviate from energy-only principles include capacity procurement or contracting by central authorities (typically the TSO) to ensure availability of capacity for specific uses[6]. Such mechanisms could be seen as market interventions that undermine the energy-only design.[7]

The key assumption of energy-only market designs is that the price structure itself will provide adequate peak capacity over the long term, based on foresight and rationality (with implicit assumptions that provision of peak capacity will resolve all other scarcities for flexibility). If there is an anticipated shortage of flexible capacity to meet a future residual peak[8], prices in these peak periods will be expected to increase (ultimately, limited only by the consumers' value of lost load), triggering an increase in forward energy (or option) prices. Annex B gives an introduction to pricing of scarcity. This will result in investment in new capacity, until the long-run marginal cost of new capacity balances the value of lost load which is avoided by the additional investment. Ultimately, the model is based on the concept that there is an economically rational level of expected unserved energy, and that it would be too costly to invest beyond this level[9], but that the market (given perfect foresight) would deliver investment up to this point.

In examining energy only market designs, the key issue is the level and distribution of 'scarcity rent' – the extent to which the market price exceeds the short run marginal cost of generation in each settlement period. There are many formulations of the theory, but the simplest is that the economic price of

6 Strategic reserves could in principle be designed to fit into energy-only principles if they are activated only as a last resort to avoid involuntary reductions of supply and the activation price is "very high".

7 Note that even the forward procurement of balancing services or reserve products or even 'warming contracts' to commit thermal units by the TSO can have a damping effect on balancing prices and undermine energy-only price formation. In some markets, mechanisms have been implemented to mitigate this effect, through administrative price adjustments to balancing energy prices (examples include Texas, GB and Ireland).

8 In earlier discussions on capacity adequacy, the discussion on adequacy was simply related to peak demand. Now the more precise formulation is residual peak demand, i.e. the peak of the difference between demand and supply from inflexible sources. This difference may also be negative, leading to a new set of challenges for system operation; as the system needs to deal with energy surplus as well as shortage.

9 In those markets for which studies have been done, the typical expected 'loss of load expectation' for a balanced system is 3 hours per year: i.e. there should be (on average) three hours in peak demand by consumers cannot be met. Algebraic formulations of scarcity price formation are available.

(day-ahead) energy in each period is a weighted average of the short run marginal cost of generation (SRMC) and the value of lost load (VOLL) when customers are cut off indiscriminately. The weighting factor between these two alternative price drivers is the likelihood that there will be a shortage of energy, the loss-of-load probability (LOLP), which in turn implies the pricing is done in advance, typically day-ahead. Thus, price in any settlement period h is:

$$Price_h = (1 - LOLP_h) \times SRMC_h + LOLP_h \times VOLL$$

$$= SRMC_h + LOLP_h \times (VOLL - SRMC_h)$$

The latter term, $LOLP_h \times (VOLL – SRMC_h)$, is frequently described as the ‘scarcity element’ of market price, resulting in ‘scarcity revenue’.

The loss of load probability is generally near to zero in most hours, but at times where there is a small margin of available capacity over demand it can increase exponentially. The scarcity element of market price is therefore highly volatile, and scarcity revenue is concentrated in a small number of hours each year. Prices should not rise above the value of lost load (if it is calculated correctly): it reflects the level at which customers would prefer to be cut off.

The economics of a sustainable power system mean that the streams of revenue cover the replacement of generation capacity when it is (economically) needed. It is uneconomic to meet all demand: instead, a system in equilibrium ends up at the point where the marginal cost of investment in new capacity (over its lifetime) balances the marginal revenue that the investment would earn (over its lifetime). Within this bigger equation, the revenue attributable to scarcity revenue will balance against the value of avoided lost load.

In recent work to set security standards for European electricity systems, typical values arrive at target loss-of-load expectations (LOLE) around 3 hours per year, with estimates of the Value of Lost Load around €5000 - €20000 per MWh[10].

Compared to any reference point:

- as the value of lost load increases, then the ideal loss-of-load expectation will reduce (i.e. as we value reliability more we should pay for more of it);

10 In appraising the capacity mechanism for the UK, a 2013 study for Ofgem concluded that the value for lost load is £16,940/MWh (with many caveats). Based on this and other analysis, a value of 3 hours LOLE has been adopted as the Government reliability standard (and a VOLL of £12,000 was adopted in price setting). https://www.ofgem.gov.uk/ofgem-publications/82293/london-economics-value-lost-load-electricity-gbpdf

CEPA studied VOLL for ACER in 2018, revealing a wide range of values. For domestic customers in Western Europe the results ranged from €5000-20000/MWh; slightly lower in Northern Europe. The value for Denmark (domestic customers) was found to be €15,730/MWh.

- conversely, as the (net) cost of building or maintaining capacity increases then the (ideal) loss-of-load expectation will increase (i.e. as reliability becomes more costly, we should get less of it).

The (net) cost of capacity is not just technology driven, as it depends on nature of capacity which is required and on the other sources of income for that capacity. In a traditional system dominated by thermal power stations, most new entry generation has been able to run for many thousands of hours each year, displacing other capacity and earning infra-marginal rent for many of those hours. In these circumstances, the **net** cost of capacity and the reliance on scarcity pricing is relatively low.

As electricity systems become increasingly dominated by wind, the required capacity margin increases, and the number of hours of operation and the infra-marginal rent accessible by even the most efficiency thermal plants is reduced. In such systems, the 'best new entrant' with the lowest (net) cost of capacity eventually shifts from being a CCGT to a peaking generator with far lower operating hours; it could be said that wind increases the (net) cost of conventional capacity. It means that the same capital cost needs to be recovered from far fewer hours by much higher prices in the energy markets.

The economics of building new peaking capacity strains energy-only markets: unlike CCGTs, these plants are very heavily reliant on scarcity revenue from a just a few hours per year[11]. A graphical illustration of this can be seen in Annex C.

As the (net) cost per MW of capacity increases, it becomes more economic to unpick the meaning of 'lost load' (which by its nature is indiscriminate) and instead to access demand response at different price levels. Thus, as the share of wind generation increases, we view the importance of demand response increases. Demand response may be considered to be selective rather than indiscriminate load reduction.

It should be noted that in well supplied markets where new entrants are not needed, only the net avoidable cost of existing capacity to avoid decommissioning needs to be covered, and scarcity prices are less important. In the Danish context, the market would rarely produce scarcity prices. The potential capacity shortage within day and in the operational timeframe is masked by the access to large cross-border capacities in day-ahead pricing.

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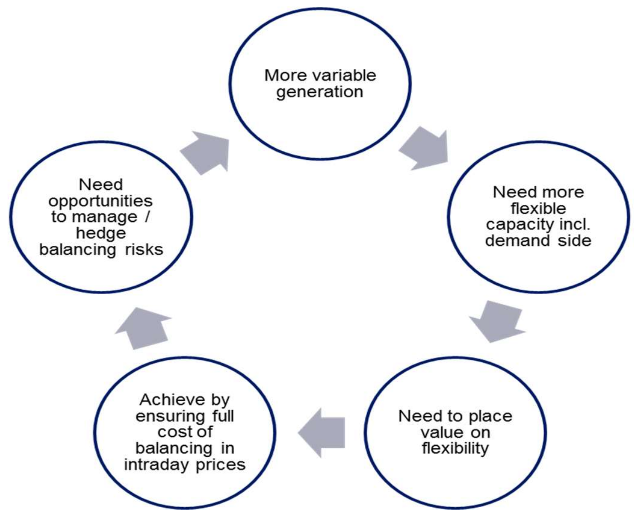
11 For example, as part of the capacity mechanism calculations in Ireland (since 2007), the cost of a 'Best New Entrant' was calculated each year. Most recently, the best entrant has been an open cycle gas turbine.
Pöyry carried out the last of these studies in 2018: "Updated cost of new entrant plant and combined cycle plant in I-SEM" for the regulatory authorities, in September 2018; this year the cheapest new entrant was found to be an OCGT peaking plant whereas the previous year it was a CCGT.
https://www.semcommittee.com/sites/semc/files/media-files/SEM-18-156a%20Poyry%20Report%20-%20Cost%20of%20New%20Entrant%20Peaking%20Plant%20and%20Combined%20Cycle%20Plant%20in%20I-SEM.pdf

Furthermore, the questions remain unanswered: Is this price level acceptable technically, politically and culturally and if not, are the hedging opportunities adequate? Figure 2 gives a graphical illustration of the challenge.

Figure 2 – Issues related to variable generation



Source: AFRY

3.3 Specific conditions for success of energy-only markets

The key issue for market design in systems dominated by intermittent renewables is that the weather-derived variation in run-of river hydro, wind and solar output leads to future market outcomes which are more volatile than in a traditional thermal system with fully dispatchable generation, and **far** more volatile in the short term than is typical in the Nordic system, which has enjoyed extensive flexibility from the hydro reservoir capacity to smooth out within-day and real-time volatility. Whether that would strongly influence Danish day-ahead pricing patterns is not clear. The move to this future system will increase the strain on transmission capacity in the Nordic market, and may create new pricing conditions, particularly in the southern parts of the Nordics and at extreme reservoir levels in certain seasons.

The various markets and system products must be defined to place value on the relevant products and services according to where and when there is scarcity. From this perspective, there are two relevant timeframes for the pricing in these occurrences of scarcity:

- In **operational timeframes**, Market Model 3.0 must price and allocate the various flexibility resources according to their economic value. The dispatch (and consumption) decisions must include the trade-off between the different needs (timeframes and locations as defined above) and of different actors including BRPs, TSOs and DSOs. The value of these flexibility services must be allowed to ripple out without barriers across trading timeframes and locations.

- In **investment timeframes**, Market Model 3.0 must support efficient decisions on investment and asset allocation. Therefore, the rules for pricing and allocation of the various services must be clear in advance to permit investors to make decisions. Furthermore, the products must be defined in a way that allows trading, hedging and adequate forecasting. This advance transparency is necessary to permit sound decisions on new investment and/or the maintenance or adaptation of existing capacity so that the flexibility services can be delivered in future.

As the Nordic system replaces nuclear with wind generation, new and more extreme operational conditions will occur, and there will be increasing need for faster response services and (perhaps) for providers of electrical inertia. Annex F gives an overview of technologies that can resolve future flexibility challenges in low-inertia systems. The product definitions and future system needs should be defined as soon as possible by the TSOs, as well as the protocols for sharing and/or trading the resources between regions, and the allocation of network capacity to the various timeframes. Without this advance work, investment decisions cannot deal with (foreseeable) flexibility needs for the future.

In each of the flexibility timeframes, there are interactions with the allocation of capacity in the grid:

- Seasonal flexibility is usually less dependent on grid capacity; it is an issue more related to energy than to capacity.
- The day-ahead, intraday and real-time markets compete directly for transmission capacity. As these markets are operated today, most of the capacity is committed to the day-ahead market, and the intraday market only gets the capacity that is unused in the day-ahead solution, with some provisions for reservation for balancing. TSOs are supposed to recalculate and release capacity according to European regulation, but historically this has happened only occasionally, and there is no working example of value-based allocation of network capacity.
- Automatic response to frequency variations has to be designed carefully and adequate grid capacity for it has to be reserved. If flexible generation capacity is reduced in an area, the capacity that is left for trading purposes is reduced.

The climate crisis is due to a market externality: the societal cost of greenhouse gas emissions is not included in the pricing of energy and other goods. Introducing a universal pricing of such emission through a tax or certificate like ETS would be the "first best" solution correcting the externality. However, carbon leakage of various types has forced the introduction of supplementary means like renewable support (RES), that undermine the effectiveness of the market in general and of the energy-only principle in particular by reducing the general electricity price level compared to an ETS-driven process.

Energy-only markets provide effective and transparent communication of time-varying marginal cost of energy in various locations, but only if the zonal split and the time resolution properly reflect variations in marginal value.

Investment incentives are distorted by the reduced price level due to RES support.

According to market principles, transmission capacity should be allocated between markets in a way that secures the same expected marginal value of transmission capacity, i.e. price differences between zones times the probability of use are the same in all markets. This is of particular importance in Denmark, where on the one hand the price differences in the day-ahead market generally are small, but market distortions cause very different supply-demand conditions closer to real time which could conceivably lead to local short-ages.

In a situation with major forecast errors, the energy-only principle calls for a price mechanism that responds to the variations in the expected supply balance, producing effective adjustments of generation and consumption. To do that, the expected situation has to be observed transparently by the Balancing Responsible Parties (BRPs), they have to expect imbalance prices and volumes reflecting the situation and they have to be allowed and able to respond to it by adjusting their balances. Greater transparency is a minimum requirement.

The arrangements for use of network infrastructure must support these two overall requirements though **transparency**, to minimise regulatory risk. In particular, the decision-making process for network build and zone definition, the capacity calculation and allocation processes for cross-zonal networks, and the tariffs and access rights for grid users must be defined clearly to allow effective optimisation of resources and decisions on investment. Delays in defining the underpinning regulatory, tariff, product definitions etc. will delay investment or add unnecessarily to risk premia.

Separately, action must be taken to enhance transparency and limit barriers to entry.

In practice, the challenge of the energy-only market in the Nordics has to date been to maintain existing generation capacity rather than to cover the capital cost of new generation (only) capacity. This has placed a low bar on the functioning of the market: Instead of relying on the expectation of scarcity revenue to materially contribute to the fixed and capital cost of new entrant generation, revenue has come from other sources (including heat production) and the extreme volatility anticipated in other energy-only markets (with occasional prices in the thousands of Euros per MWh) has not occurred.

4. APPRAISING DANISH MARKET AGAINST THESE REQUIREMENTS

The criteria for an economically efficient market design based on energy-only principles are discussed in chapter 3. The main success factors for the Danish electricity market going forward can be summarised as reaching the 70% decarbonisation target while maintaining:

- security of supply by providing adequate flexibility, covering residual peak capacity, within-day and real-time (the seasonal energy needs are not expected to be a main concern in Denmark for some time);
- economic viability by correctly remunerating the flexibility products needed as well as communicating well in advance to secure investment decisions; and
- the stability of arrangements by monitoring entry barriers, transaction costs, freedom of choice, maximising transparency, minimising regulatory risk and enabling demand side potential.

The specific requirements for MM3.0 design should reveal the value of different services, in ways which allow effective allocation of flexibility resources in operational timeframes as well as effective decision-making in investment timeframes.

Even if these economic criteria are met, there are risks relating to the political acceptability of the outcomes. For the energy transition to be acceptable to consumers and politicians, the allocation of costs and risks between different stakeholders, and the co-dependence with neighbours may be a limiting factor.

In this section we look at some of the practical barriers to achieving a market-based vision in the context of 2030 Denmark in which sustainability – the first leg of the trilemma – is assumed to be prioritised.

4.1 Energinet's analysis

During 2014-2015 Energinet conducted the Market Model 2.0 (MM2.0) project. In this project the concept of an energy-only market model in a Danish context was analysed. The overall focus areas for the analysis were:

- Investigating how to obtain payments and forward visibility of payments to provide a framework for acting in a flexible manner and invest in flexibility.
- Establishing ways to introduce strategic reserve to ensure capacity in extreme situations.
- Investigate a capacity market designed as a direct payment for capacity.
- Other possibilities were found to be out of scope for an energy-only market model in a Danish context and were not analysed in detail:
  - Capacity payments in the form they are used in Spain or Ireland; and
  - Theoretical market models where consumers enter into long term forward contracts with producers.

Following the MM2.0 project, Energinet has taken steps towards preparing for the establishment of a 300 MW strategic reserve to be made towards 2030 as a last resort if "*market reform does not have sufficient effect on capacity adequacy or if the capacity situation is further exacerbated*" (Energinet, RFE 2019). Energinet is setting up pilots introducing consumers as suppliers of system services, exploiting flexibility from EVs, heat pumps, batteries and industry.

According to Energinet, the peak capacity situation is at present deemed to be adequate in all timeframes. Energinet is however concerned that in DK2, as loads and system needs increase, there may be insufficient peak capacity in 2030 to prevent involuntary load shedding in a number of hours per year that is too high. Opportunities for market-based capacity increases are limited, and in particular, new interconnections are not seen as socio-economically profitable:

- The synchronisation of DK 2 to the Nordic system is through Sweden (SE4), itself with a tight capacity situation due to constraints in the Swedish system. Extending the AC capacity to SE4 therefore would therefore not make much of a difference.
- Extending capacity with NO2, DK1 or SE3 would be on new DC connections and therefore expensive, without sufficient price differences to pay for them.
- Extended capacity with Germany would have limited value due to domestic German capacity constraints which limit flows towards Germany at times of high wind.

4.2 Danish and Nordic markets in practice

In traditional energy-only markets, electricity prices are supposed to be the main signal of scarcity and the trigger for generation investment. In future, scarcity needs will take different forms and the pricing arrangements must reflect these new complexities.

4.2.1 Seasonal balance

In most contexts, the Nordic market is energy-constrained and not capacity-constrained. Referencing our four scarcities, the hydropower provides flexibility to cover all of the time-frames, including **residual peak capacity** (flexibility 2), capacity to adjust for dispatch errors **within day** (flexibility 3) and close to **real time** adjustments (flexibility 4). The challenge for flexibility related to hydropower has mainly been **seasonal** (1), the risk of energy deficit in dry years. This has usually been an issue for the entire Nordic market, even though we have seen localised spring crises in dry years in Norway. Since expected scarcity has previously been related to energy rather than capacity, capacity markets have been seen as irrelevant.

Until now, back-up for Nordic dry year situations has been provided by fossil-fuelled generation in Denmark and Finland. In the future, the Nordic market (Norway and Sweden) will rely on (mainly off-peak) imports on cross-border interconnectors. In Denmark, seasonal energy supply will probably not be a problem (at least until there is large scale electrification of heating).

4.2.2 Day-ahead balance

Both zones of the Danish market are strongly connected under the European day-ahead market coupling, but neither of them is self-contained. A supply shortage in one of them will therefore – typically – be part of a more widespread shortage[12]. Prices in the Danish zones are set by prices in other parts of the European market, and they do not reflect the actual supply/demand situation purely within the Danish zones. Scarcity of residual peak capacity day ahead looks very unlikely. Instead Denmark will increasingly be dependent on its neighbours for crucial services, including peak capacity.

Based on the four timeframes of scarcity set out in section 3.2 above, (market-wide) capacity mechanisms tend to focus on flexibility 2 (capacity to meet residual peak demand) while ignoring the others. We therefore support the conclusion of Market Model 2.0 that a formal capacity mechanism would not meet Denmark's future needs. Instead, a system of market arrangements should be implemented, in which scarcity in each of the four timeframes and the various locations is rewarded a balanced way, permitting decisions to be taken effectively by TSOs, asset owners and investors:

- operationally, allocating network capacity and flexibility to the appropriate timeframe and use; and
- long term, related to closure of and investment in generation and transmission assets.

4.2.3 Intraday rebalancing

In a future market dominated by renewables, the importance of the intraday timeframe will increase. The quality (and purpose) of the day-ahead balance is getting weaker, and market participants will have to adjust through intraday trading. If the liquidity of the intraday market is not improved, the residual imbalances that must be tackled through the balancing market may grow to critical levels. To prevent that, a liquid cross-zonal intraday market, enabling the trade of surplus flexibility, will have to be developed[13].

4.2.4 Real-time balancing

In each operational time unit and a period before, the TSO has a balancing monopoly in the Nordic system[14]. Based on bids and offers, the TSOs buy (or requisition, if offers are mandatory and there is no option payment) options to increase or reduce generation after Gate Closure. Bids and offers are put on common merit order lists and exchanged between TSOs according to what is commonly called the TSO-TSO model. Previously, TSOs were able to reserve capacity on zonal borders for balancing purposes. In practice, however, possibilities of reserving capacity on international borders have been limited

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12 It is possible that shortages in Denmark may occur due to restrictions on flows from neighbouring countries, either due to technical failures or national security of supply measures by other countries. It is important to have a good mutual understanding of these possible eventualities.

13 Germany has implemented 15 minute intraday auctions which have attracted liquidity and reduced the need for TSOs to take balancing actions.

14 In Belgium and the Netherlands, self-balancing, where market participants are permitted to adjust their schedules right up to real time in response to indications of the overall system balance is implemented with good results.

and are further reduced in recent updates of European (and Nordic) regulation.

The sharing of other system services between TSOs is under development; and congestion management is a particular cause for concern (for example causing wind generation to be de-loaded in Denmark to deal with congestion within Germany). Arrangements for allocation of network capacity to these other services (and to the intraday timeframe) are yet to be agreed.

4.3 The Trilemma perspective

4.3.1 Sustainability (decarbonisation)

As mentioned in section 2.2, Denmark has an ambition to achieve 70% decarbonisation in the energy system by 2030, and we believe that most of it has to be delivered by the electricity sector in the form of renewable generation and electrification, i.e. new electricity demand from other sectors. The goal of Market Model 3.0 is to adapt the Danish electricity market design so that the sustainability (decarbonisation) target can be delivered as efficiently as possible.

We have established above that access to flexibility in different timeframes will be the main stumbling block if electrification is an important part of the route to decarbonisation. Electrification will be based on large quantities of electricity from wind and solar going into main consuming sectors:

- transport;
- manufacturing industry; and
- heating/cooling.

Electrification of transport (smaller vehicles and coastal ferries) will increase volatility in the Danish consumption pattern, and may in return provide important fast, short-term flexibility, but probably only after 2030, since the smart-grid capability required may take longer to develop.

There is a great potential for electrification of the heating sector in Denmark, and the development is well under way. It is important to note that the heating sector can potentially put more pressure on the seasonal flexibility of the Danish electricity market. On the other hand, the heat sector will be able to provide short-term flexibility by turning off both direct electric water heating and heat pumps. It is important that flexibility concerns are included in the design of electrification solutions to make electrification a resource, rather than a problem for the electricity market. A more detailed discussion of electrification can be found in Annex D.

Compared to the other Nordic countries, electricity demand in Denmark has been more predictable and less dependent on business cycles and temperature. On the other hand, since customers are used to high electricity prices (and taxes) and have developed highly efficient electricity use, price sensitivity of demand is low. This may change in the 2030 world, especially with introduction of electric heating, electrically driven cars and ferries.

4.3.2 Reliability (security of supply)

The main areas of concern in a 70% decarbonised world will be in the timeframes that are closest to operation, providing capacity to correct day-ahead forecast errors and to balance the system. Thermal generation (condensing and CHP) based on coal and biomass is currently both the main source of heat and a key provider of such flexibility. Reducing operational hours of CHP plants by introducing more electricity-based heat may reduce emissions, but will make it more difficult to keep this capacity viable long term.

However, since interconnection capacity provides more than enough total capacity, the main flexibility challenges are tied to the intra-day and real time flexibility. Intraday liquidity is weak, mainly due to limited allocation of cross-border transmission capacity, thus straining access to upregulation generation capacity

Electrification, of transport in particular, may create congestion in distribution networks related to charging of batteries. The management of such congestion will to a large extent have to be managed by DSOs procuring local demand-side flexibility at the same voltage level. This creates several types of challenges.

- Firstly, markets that include all relevant parameters like grid topology and a finer geographical resolution related to bids will have to be developed. Alternatively, the norms of firm access and equal network tariffs for customers at the same voltage level will need to be reviewed.
- Secondly, there is a need for a new protocol for coordinated congestion management between DSOs and TSOs, avoiding flexibility actions in opposite directions.
- Thirdly, incentives towards BRPs to reduce overall imbalances should be implemented in a way that self-balancing does not create new local imbalances.
- Finally, the procurement of flexibility from BRPs, DSOs and TSOs should be coordinated, preferably through market arrangements. This will be increasingly important in the 2030 world.

4.3.3 Available measures to maintain reliability

Figure 3 summarises the availability of relevant capacity and flexibility in the different timeframes, looking forward to 2030 and the possible measures to mitigate shortages. In normal operational conditions, the interconnector capacity covers the seasonal variations in Denmark as well as shorter term variations in the residual demand peak. The flexibility need for the later timeframes in the operation cascade, is today mainly covered by flexibility in the Danish CHP units.

Weaknesses in the mechanisms allocating cross-zonal transmission capacity may give efficiency losses inasmuch as it reduces access to lower cost flexibility from neighbouring countries. In the situation as expected by Energinet in 2030, this weakness may give rise to a real shortage in flexibility to correct dispatch errors and cover operational needs, particularly in DK2.

Figure 3 – Availability of relevant capacity and flexibility

		Volatility timeframes			
		Seasonal energy	Residual peak capacity	Within day	Real time
Present situation		√	√	√	√
BAU 2030	DK1	√	√	√	√
	DK2	√	√	?	?
Po ssi	Demand response	0	0	(+)	(+)
	- Green mobility	0	0	(÷)	(÷)
	Grid investment	0	0	(+)	(+)
	- Inter-connectors	0	0	(+)	(+)
	Electricity storage	0	0	(+)	(+)
	Power to heat	(+)	(+)	+	+
	Power to gas	(÷)	(÷)	(÷)	(÷)
	Market reform	0	+	+	+

√	Adequate capacity	?	Potential deficit
+	Significant effect	0	No significant positive effect
(+)	Cost effective?	(÷)	Not (cost) effective, at least not before 2030

As a mitigating measure, increasing the price response in end-user demand should be encouraged. At present, the potential is limited, but may increase with a higher degree of electrification. As a subset, green mobility is considered. A significant share of small cars and ferries will have to be electrified, and initially, green mobility will increase demand volatility and create local congestion in the grid. However, the flexibility provided by green mobility will mainly be used to solve these short-term problems, and given the right incentives, green mobility may be an important flexibility provider. On the flipside, green mobility may even add to the challenges before 2030 if incentives for charging at the right time and place are not effectively implemented. In the longer term, spare capacity in mobile or stationary batteries related to mobility (e.g. second-life batteries) may contribute even more to overall flexibility.

Development of the grid, including international interconnectors is hardly a cost-effective measure to improve security of supply. The present grid capacity is large and diversified, and the main issue is related to its use in different timeframes.

Storage of electricity in batteries etc. is still expensive and will only contribute in the intraday and operational timeframes. Flexibility built into an electrified heat sector with increased heat storage and a combination of various types of heat pumps and direct heating may provide significant flexibility in all timeframes, competing with and supplementing import.

Completely removing emissions from the gas sector may be done by producing hydrogen through petrochemical processes (with CCS) or by electrolysis of water using emission-free electricity. Neither of these processes is cost effective with the present technology, and another approach, testing and developing solutions may be more appropriate. This is one of the few sources of seasonal flexibility, which will be needed in a future with much higher levels of electrified heating.

Reforming the day-ahead, intraday and balancing markets, allowing a delay or reversal of the commitment of the physical allocation of transmission capacity from the day-ahead market to the other two markets, could have a major impact on security of supply. This would have to be something else than the measures that are being implemented. EPADs, FTRs, capacity auctioning etc. are mainly intended as hedging tools, and will have limited effect on physical operation or access to flexibility.

Energinet's analysis suggests that the focus points for the future must be on maintaining enough flexible capacity and to keep an eye on transparency and cooperation towards neighbours. This highlights the fact that investment needs are a regional rather than purely a national issue.

This translates to a political issue: are there circumstances in which Denmark's neighbours become reluctant to support Denmark's security? All trade must have benefits for both sides: there must be adequate payment (by Denmark) for the range of flexibility services which it takes from its neighbours, and there must be the potential for neighbours to benefit from Denmark's potential for green energy exports without this becoming a political barrier within Denmark.

4.3.4 Affordability (short- and long-term economic efficiency)

The distribution and volatility of costs and prices are in principle market outcomes: They are not economic challenges in their own right, but may present political challenges. These will need to be anticipated and, where possible, mitigated. As shown in Annex E, downregulation, i.e. reduction in (wind) power generation to meet transmission constraints, gives a significant loss of potential (wind) energy production in Denmark. This is mainly due to within-day redispatch related to congestion in Northern Germany, and the obligation for the TSOs to offer more interconnector capacity to the day-ahead market than can be used in reality [15]. Future requirements to offer a

15 In relation to the situation on the border between Denmark and Germany, there has been an increase in the need for locational redispatch at times of high wind generation, since export capacities from Denmark are set artificially high in the day-ahead timeframe due to the obligation to offer more interconnector capacity to the day-ahead market than can be used in reality. The subsequent reduction in (Danish) wind power generation to meet transmission constraints, gives a significant loss of potential (wind) energy production in Denmark. We expect

minimum of 70% of rated interconnector capacity to 'the market' mean that this locational requirement for inter-zonal flexibility will persist. The way in which this rule is implemented is potentially one of the barriers to the effective 'rippling' of scarcity between markets.

The way in which price zones are defined and how interconnector capacity is calculated and allocated between different timeframes will influence what flexibility services have value, where and when. This is important for the 2030 energy market design. The intraday redispatch arrangement towards Germany is an actual example where market participants' incentives for self-balancing are limited and may lead to inefficient outcomes.

We see that the major challenges to the development of MM3.0 in the 2030 context relate to inefficiencies which unnecessarily raise the costs.

The distribution and volatility of costs and prices are in principle market outcomes: They are not economic challenges in their own right, but may present political challenges.

The transition phase is as important as the target: ten years is not enough time to develop new technology, and the task will be to reduce greenhouse gas emissions to 30% of 1990 levels using existing technology. One of the risks of fast transition relate to choices that unnecessarily raise the costs. There are significant uncertainties which place risks on investors, and there is a need to give as much certainty as possible to limit capital costs. In such circumstances, it would be favourable to preserve as much as possible of the infrastructure that can be useful in the future, taking account of opportunities related to technology development.

We recommend that more detailed system studies are performed against credible 2030 scenarios to investigate these needs. Specifically, within the timeframe 'real time' (which equates to post-gate closure actions) there will need to be development of products reflecting very short-term capabilities; for example, in Ireland there are now products which target inertia from large thermal units. Development of new products has also started in the Nordic region using fast reserves (FFR) to manage the trend of decreasing inertia. The first version of FFR in the Nordics will be implemented in 2020.

4.3.5 Operational timeframes

The energy only market model principle has served the Nordic Power Market well, and scarcities have mainly been seen at an energy level. Going into the future, scarcities are expected to move much closer to real time as Denmark and neighbours are transforming their energy system towards decarbonisation. The future world is more complex including scarcities in multiple time dimensions and locations.

Critical design issues that need to be solved in short term are:

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this problem to be temporarily reduced with the start-up of the new DC cable between Germany and Norway (NordLink) but will surely be a major issue in the expected 2030 conditions.

- define products and markets suitable for all 4 clusters of flexibility and for the various locations (including inter-zone, intra-zone and at distribution level), to reveal economic value and to assign resources effectively between timescales, locations, and between the competing buyers of services;
- the ripples of prices must be allowed to spread without obstacles across locations and timeframes; and
- allocation of flexibility resources to the appropriate timescale and location is an increasing challenge.

One important issue to highlight in the Nordics is that the intraday market is not fully functional, with very poor liquidity due to i.e.

- allocation of network capacity between timeframes is inadequate (all capacity available day-ahead); and
- some markets, including Denmark have day-ahead balancing obligations, taking volume out of the intra-day market.

4.3.6 *Investment timeframes*

The market design should support investment decisions even though, due to the high degree of interconnection, new capacity is hardly needed in Denmark in the foreseeable future. The reason is that longer term investment type decisions need to be made for the existing capacity. Good governance and forward-looking transparency and (where relevant) opportunities to hedge risk is needed for optimal to allow investment decisions. This includes clarity on the vision, the incentives and the decision-making processes for transmission and distribution network investment, network access and pricing. Moreover, the market design should be acceptable to stakeholders within Denmark and in neighbouring countries – based on both allocation of cost and risk – to mitigate the likelihood of ad hoc political intervention.

It should be noted that ensuring forward looking pricing in the different timeframes is a very challenging task, since not all of the needed future products exist today. The starting point for intra-day and real-time product definition is the transparency of the TSOs view on the system need.

Traditionally, the demand side has not been very flexible. However, this might change when new demand enters the market mainly in the form of electrified transport and heat. If handled in an intelligent way, the new demand will provide important short term flexibility. On the other hand, electrified heating will introduce new needs for flexibility in the seasonal dimension.

4.3.7 *The regional dimension*

The picture is further complicated by the fact that Denmark in most cases is a price taker, depending heavily on other systems. Investments are not necessarily needed in Denmark, it is vital to look at a broader region. In real-time balancing, for example, prices are to a large extent set by a common Nordic merit order. This weakens the incentives to invest in flexibility in Denmark as such, which could be perceived as a problem from a political point of view.

Working together with the neighbours to solve regional design issues is equally – if not more – important for Denmark as designing their own market. We can mention a few issues to be monitored going forward:

- There is a question whether scarcity volumes would be reflected in imbalance settlement if there was actually a shortage and load reductions.
- Are price caps, strategic reserve, bidding restrictions etc. limiting the price formation?
- There is a concern that forward capacity procurement (e.g. RKOM) will limit the ability of balancing prices to remunerate full long run marginal cost.
- What are the consequences of non-optimal design in neighbouring countries, for instance Germany having one price zone?
- Prices have been artificially low due to subsidised renewables and hence an oversupplied market. Due to very ambitious renewable target at a regional level, continued support of renewables could put even more pressure on energy prices.
- There is currently no liquid forward hedging products between price zones, limiting the market players ability to make proper investment decisions.

4.3.8 Transition towards a low carbon energy system

Denmark has already started on its transition towards a decarbonised energy system. In this transition period, it is important to ensure that long term goals are met in an efficient way. If parts of the existing infrastructure need to be decommissioned, timing is important. Due to lack of clarity in long term market arrangements or available technologies, investment decisions might be postponed.

An important example is the gas grid, that might provide dearly needed flexibility in the future. This might justify some market intervention to avoid closing flexibility options. Another important part of the transition is the process of electrifying the heat and transport sectors. It is important to ensure that there are no barriers to electrification and that newly-electrified demand is designed to add flexibility to the electricity market where appropriate.

4.3.9 Market stability

When transforming the energy sector and adapting the electricity market, it is important to make sure that the market is well functioning and stable. Important aspects to monitor are liquidity, which is already an issue in the Nordic intra-day market, forward transparency by TSOs and governance of non-market based decisions such as grid investments.

4.3.10 Political stability

Denmark has a tradition for political consensus on energy policies. Early December 2019, all political parties signed the new climate law committing to the earlier mentioned 70% decarbonisation target. This stability is important, since political decisions set the boundaries for the electricity market design:

- setting the sustainability targets;
- defining the reliability targets explicitly or implicitly and
- influencing the affordability by various types of support schemes.

In a renewables-dominated market, volatility, risk and complexity are higher, and it is important that regulatory and policy risk is not increasing and adding to the challenge:

- Denmark is relying on neighbours to ensure security of supply. Is the degree of self-sufficiency acceptable?
- Are the neighbours happy for Denmark to rely on them, and how reliable are they?
- Is Denmark happy to export its cheap wind for the benefit of its neighbours?

The transition towards a low carbon energy system has already started. Denmark must make sure that the right closure decisions are taken today based on an understanding of future needs.

5. CONCLUDING REMARKS: GETTING TO A FUTURE-PROOF ENERGY-ONLY MARKET

5.1 Summary and conclusions

It is agreed that the principle – that electricity market design shall be based on the energy-only design – has served the Nordic Power Market well. Scarcities have mainly been seen at an energy level. Going towards decarbonisation, however, scarcities are expected to move much closer to real time as Denmark and neighbours are transforming their energy system. It is important that the market design covers all timeframes, in this report defined as seasonal, residual peak, within-day and real-time; as well as the various locations down to distribution level.

The Danish power market is a well interconnected small market linked to large neighbouring markets and Denmark cannot fully design its own market. Most of the time, price formation will be dependent on prices in neighbouring markets. Hence a good understanding and close relations to neighbouring systems is vital.

Critical design issues that need to be solved for the short term are:

- allocation of cross-zonal of transmission capacity between timeframes, providing more capacity for the intraday market;
- definition of a succession of products and markets that integrate all four clusters of flexibility in order to reveal economic value and allocate resources effectively between timescales and location;
- design of new markets that integrate the actions of new groups of active participants in the (near) operational timeframes; and

- Review market pricing, making sure that the ripples of anticipated shortage are allowed to spread without obstacles across locations and timeframes.

In the longer term it is important that the market design can support investment decisions, either in new or existing capacity by:

- Ensuring good governance, forward-looking transparency and adequate hedging opportunities.
- Mitigating the likelihood of ad hoc political intervention by making sure that the policy is acceptable to stakeholders within Denmark and in neighbouring countries under foreseeable market outcomes.

In order to have efficient price formations in shorter timeframes, demand side flexibility should be activated and allowed to participate in the various markets.

5.2 Recommendations

We have made some considerations about the further work needed for the Danish power market. First, it is important that the conclusions of this analysis should be examined and underpinned by quantitative analysis.

Table 1 below sets out some of the key design decisions to be made for MM3.0 and the requirements of different participants and stakeholders to deliver a successful outcome. Further, Annex A outlines the critical questions to be answered by MM3.0. Our recommendations can be summarised as follows:

Big picture technology choices

We believe that the electricity sector will deliver most of the decarbonisation needed in the form of renewable generation and electrification, i.e. new electricity demand from other sectors, provided that:

- the vision for the Danish energy system is widely accepted and consistent over time;
- markets provide forward vision to support investment decisions; and
- electrification is prioritised, coordinated and designed so that the short term flexibility can be utilised.

Flexibility product definitions, pricing and trading arrangements

In the low carbon electricity market there is a need for to integrate all four clusters of flexibility in order to reveal economic value and allocate resources effectively between timescales and location, requiring:

- correctly accounting for imbalance quantity and balancing price formation in the event of scarcity; and
- that product definitions and future system needs are defined as soon as possible by the TSOs, as well as the protocols for sharing and/or trading the resources between regions, and the allocation of network capacity to the various timeframes. Without this advance work, investment decisions cannot deal with (foreseeable) flexibility needs for the future

Network and capacity allocation

Market-based allocation of cross-zonal transmission capacity between time-frames is critical for a Danish intraday market, but the methodology is not well developed, and would require further analysis. One promising idea to improve the allocation between time frames would be to develop tradeable transmission rights ("Revealing the value of Flexibility", Pöyry 2014)

Interconnector and TSO network build

Interconnector and transmission network investments needs to follow a well communicated clear decision making process to inform private investment decisions.

Investments which are have positive welfare benefits should be taken forward and there needs to be an agreed process to progress Nordic initiatives ("Fortum energy review: Grid planning", Pöyry for Fortum 2019)

DSO network access and build

Electrification, of transport in particular, may create congestion in distribution networks related to charging of batteries. This creates several types of challenges:

- markets that include all relevant parameters like grid topology and a finer geographical resolution related to bids will have to be developed;
- grid access rights, connection processes and charging mechanisms should be reviewed as part of the future market;
- there is a need for a new protocol for coordinated congestion management between DSOs and TSOs, avoiding flexibility actions in opposite directions; and
- incentives towards BRPs to reduce overall imbalances should be implemented in a way that self-balancing does not create new local imbalances.

Transitional issues

Denmark has already started on a transition towards a decarbonised energy system. In the transition period it is important to:

- Avoid irreversible decisions (like premature closure) related to important infrastructure (in particular production, storage and distribution of gas and heat). This infrastructure, while it might not be important in the transition phase, may be necessary for longer term efficiency.
- Create coordinated financial conditions for regulated and nonregulated parts of the energy sector, making sure that there are no barriers to sector coupling, allowing other sectors to supply flexibility to the electricity market.

Table 1 – Key design decisions and requirements

	BRPs in operation	Market investors	Danish stakeholders	International governance
Big picture and technology choices		Predictability for investment Transitional support and adjustment	Consistency of vision Public acceptance Coordinated and prioritised sector coupling: heating, transport and gas	Broad consensus on trading and exchange of flexibility
Interconnector and TSO network build		Clear decision-making process to inform private investment decisions	Dealing with ▪ visual impact ▪ cost allocation ▪ cost volatility	Process to deliver profitable investments ▪ conflict solving ▪ cost allocation ▪ cost volatility
Network capacity and allocation	Allocation of transmission capacity bet-ween time-frames	Clear decision-making process to inform private investment decisions	Transparency of price zone decisions	Zone arrangements Capacity calculation Cross-border capacity sharing EU compatibility
DSO network access and build	Effective DSO TSO coordination of congestion management	Clear intentions re. DSO needs for flexibility	Incentive regime Clear network access and pricing regimes (e.g. non-firm access or variable grid charges)	Agreement on prioritisation between local and cross-border use of resources
Flexibility product definitions, pricing and trading arrangements	Product defini-tions adapted to pot. suppliers Effective trading and pricing Effective allocation bet-ween uses	Forward visibility of system needs Suitable flexibility product definitions and procurement arrangements Good hedging opportunities	Ensuring that there are no barriers to participation of small scale resources and that demand side participation is maximised	Cross-border product definitions Clear and transparent cross-border agreements on protocols in times of shortage
Specific transitional issues		Incentives to prevent premature closure of flexible capacity Incentives to include flexibility into new demand and supply assets	Sector coupling to heating, transport and gas sectors based on existing technology Relaxing unbundling regulation for integrated projects? Transitional support for demand side participation? Focus on liquidity and market power in new markets	

ANNEX A – QUESTIONS TO BE ADDRESSED IN MM3.0

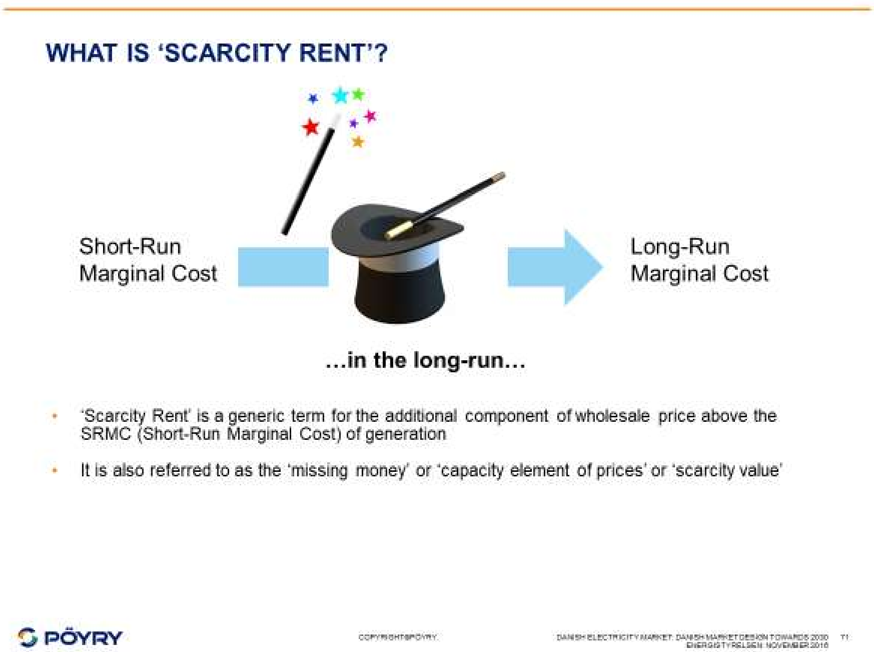
Critical questions which MM3.0 must address are:

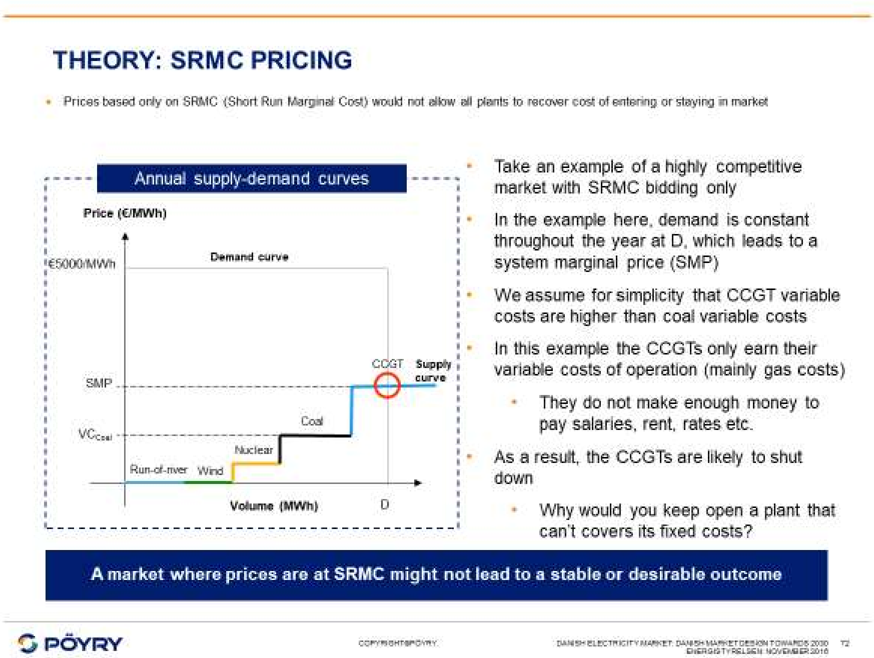
- What are the future credible scenarios (generation, demand, network capacity) for which the market must be capable of dealing?
  - How fast will the transition be?
  - Will there be targeted support for any of the technologies (e.g. EV charging), and what will be the cost expectations?
  - Is the vision compatible with/shared by neighbouring countries?
  - Are there binary big-impact issues which need further investigation e.g. future decommissioning of nuclear in Sweden, major interconnection?
  - To what extent are there interactions/contradictions with the Danish government's vision e.g. for industrial policy (offshore wind development ambitions)
- In those scenarios, what are the flexibility needs?
  - Note that the scarcity needs of DK1 and DK2 will differ.
  - How will the future flexibility products be defined and procured/traded, and who will be the buyers?
  - To what extent will these products be Danish-only and/or fit with those of neighbouring countries?
  - What is the process to agree the products (including alignment with neighbours and Network Codes)?
- What are the high level costs, how evenly is the cost spread and to what degree is there volatility in cost faced by some actors (or investors)
  - Will there be stranded assets belonging to politically influential actors (e.g. municipalities)?
  - Will the uncertainties for investors be manageable?
  - Is the cost distribution or volatility likely to trigger political intervention, and if so can it be done in a controlled way?
- What are the arrangements by which network needs and rights will be defined (including access rights and grid tariffs)?
  - How will network capacity be allocated between the various timeframes?
- How will the competing needs of market actors, TSOs (including cross-border) and DSOs be met, given that some flexibility services are exclusive whereas others are complementary?
  - How can flexibility providers combine complementary revenue sources, and what visibility will they have when considering investment decisions?
- How will the sharing of costs and benefits between countries be dealt with in different conditions (including unfavourable cases)? How will agreement be reached on key decisions?

- Neighbouring markets are not perfect: which distortions will have an impact on Danish market outcomes (e.g. the capacity restrictions within the German price zone, restrictions on access to Poland)?
- What regulatory incentives will network operators have to build assets (including interconnection) where it is economically valuable, and to buy flexibility services where that has greater value? (e.g. TOTEX incentives)
  - How transparent is the investment process especially for major cross border projects?
  - Is there a process to ensure that projects with positive international cost-benefits are built?
- To what extent will market outcomes lead to variation in costs to different classes of consumer (e.g. in different parts of Denmark)? How will these be communicated and/or mitigated without risk of ad hoc intervention?
- Will barriers to entry and transparency be addressed consistently?
- From an investor's perspective, what are the major risks to building the capacity which the system will need?
  - How might these be mitigated?
- Are there specific transitional needs which must be considered?
  - To avoid closing flexible capacity which will be needed later?
  - To ensure flexibility is baked into new demand/generation sources if it will be needed later?

ANNEX B – SCARCITY RENT ILLUSTRATION

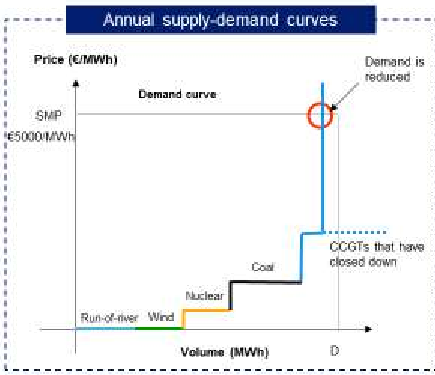
This Annex is taken from a previous (2016) project for Energistyrelsen in which we looked towards market design criteria for 2030.





IMPACT OF SRMC PRICING

- Plant exit could lead to supply shortages and very high price spikes



- Since those CCGTs that could not cover their fixed and variable costs have shut down, prices now spike to very high levels
- CCGTs close down as a result of not being able to cover their annual fixed costs
- This continues until sufficient plant have retired so there is not enough capacity
- The prices spike to the Value of Lost Load (VOLL)
  - In this example €5000/MWh
- Generally, this would not be regarded by consumers as a desirable outcome

A market where long-run marginal costs are recovered through demand side shedding is not an ideal outcome, despite being an economically rational outcome

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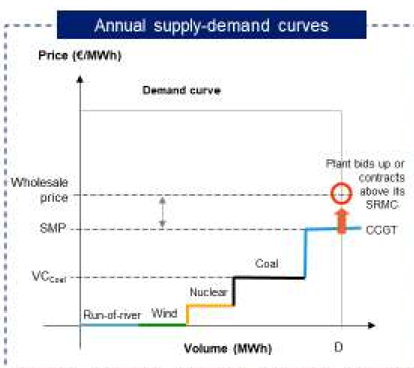
MISSING MONEY SOLUTION: SCARCITY RENT

- One solution is that the wholesale price rises above the SRMC due to an implicit Scarcity Rent. This results from generators bidding above SRMC



- The 'Scarcity Rent' concept does not specify exactly how this bidding up occurs, just that it does occur
  - It could be a specific company pushing up bids/offers, it could be a group acting together.
  - It could be peaking plant (OCGTs) pushing up prices, or other technologies
  - It could be due to bidding up, or withholding capacity
  - It could be due to market power
  - It could be due to market abuse
- **The outcome (prices above SRMC) is much more important than the mechanics for delivering outcome**

Recovery of the Scarcity Rent occurs in a complex fashion but the act of pushing prices above SRMC does not necessarily constitute market abuse/power

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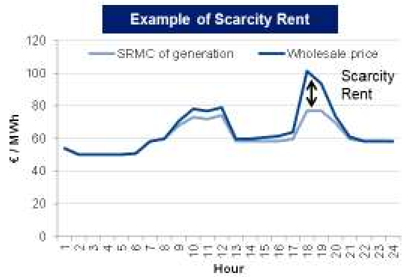
WHAT IS SCARCITY RENT?

- Prices can rise above the short run marginal cost of generation in order to keep enough capacity online – this is called Scarcity Rent

- For generators to recover their annual fixed costs and their capital costs, wholesale prices in the long-term probably need to be above the short-run marginal cost (SRMC) of generation
- **'Scarcity Rent'** is a generic term for the additional component of wholesale price above the SRMC of generation. It is also referred to as the 'missing money', 'value of capacity' or scarcity value



How the Scarcity Rent appears in a market depends on the market design and the market structure

- A market with an explicit capacity payment mechanism may not have any Scarcity Rent in the (residual) wholesale price
- A highly competitive market with a large number of new entrants may have a lower Scarcity Rent than a less competitive market. This does not mean a lower Scarcity Rent is a 'better' outcome

Scarcity rent appears by generators bidding or contracting above SRMC

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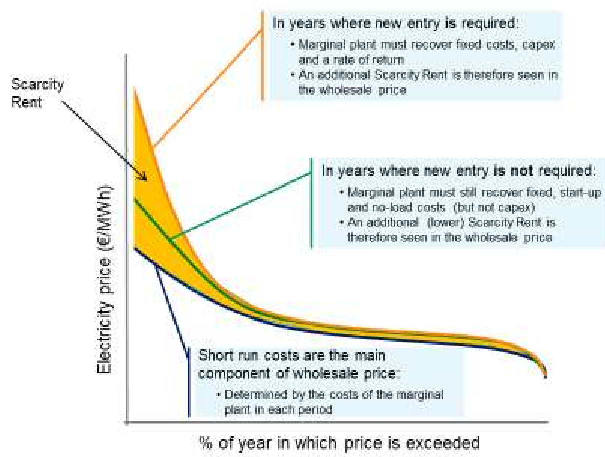
SCARCITY RENT VARIATION

- Scarcity Rent will vary from one year to another, depending on how tight the system is and whether new entry is required



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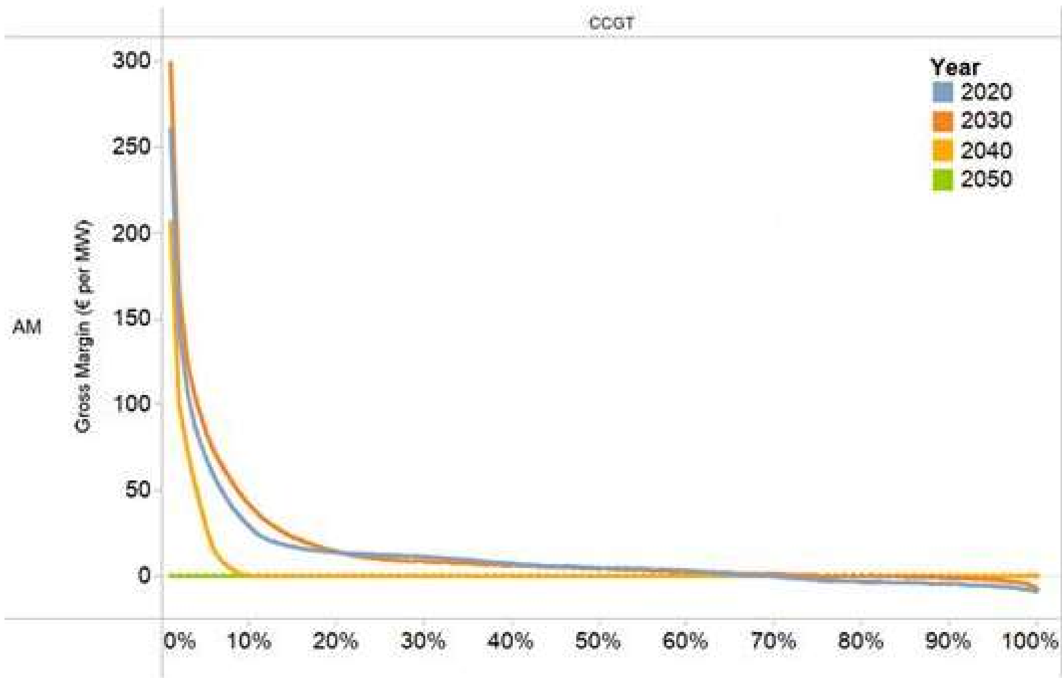
ANNEX C – PEAK PLANT REVENUES IN RES DOMINATED SYSTEMS

Figure 4 below is illustrative, based on previous work by AFRY to consider the net energy revenue for a nominal new build CCGT over time, as the share of renewable generation increases.

Figure 4 – Modelled gross margin for a new CCGT as wind penetration increases



Source: AFRY

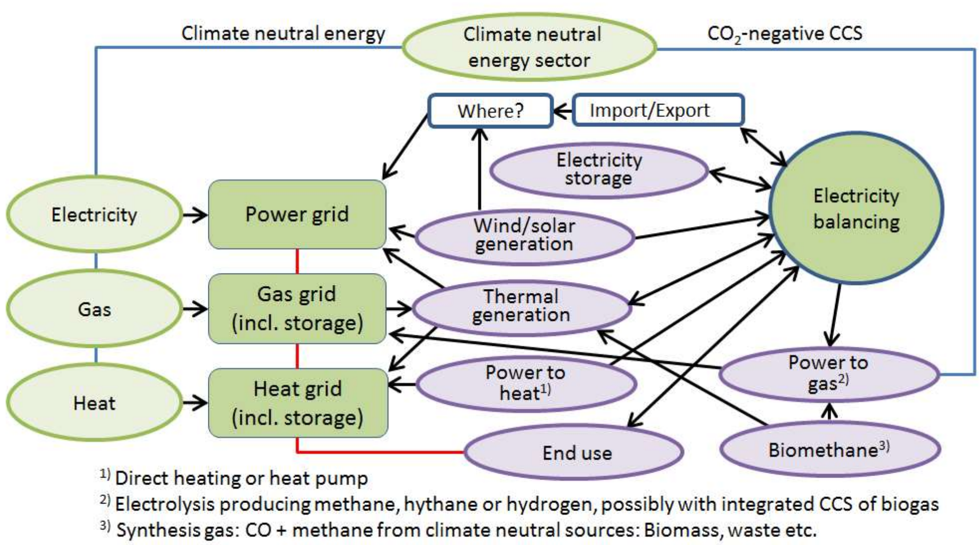
ANNEX D – SECTOR COUPLING

Coupling the energy sectors (electricity, gas and heat) to each other and to other sectors will be the only way of achieving CO2-neutrality in energy consumption. Except for hydropower plants with storage of water in reservoirs, the dispatch flexibility in a CO2-neutral electricity sector is low. Most sources of flexibility are expensive, and the introduction of a dominant share of intermittent generation increases the need for back-up capacity.

There are two main options for reduction of CO2 emissions in the entire energy sector, electrification based on emission-free sources and CCS (Carbon Sequestration and Storage) based on fossil sources. Going the CCS route has major implications (technological and in terms of investment): Selection of emission neutral energy carriers (liquid and/or gaseous), development of CO2 sequestration, collection and deposition infrastructure and conversion of infrastructure for distribution and consumption. In the long run, the solution will clearly be a combination of the two. In fast transition now, however, electrification will be the main option. The CCS option need more time than is available to develop cost-effective technology, do the main structural choices and invest in functional infrastructures.

Figure 5 shows how sector coupling, using the implicit storage capacity in the existing heat and gas infrastructure, may provide flexibility to an emission neutral electricity sector.

Figure 5 – How to achieve CO2-neutrality through sector coupling



Source: AFRY

Electrification of Danish manufacturing has a limited potential. The main energy non-electricity energy consumers are cement production and oil refineries, and due to the technology, only a small part of their consumption may easily be electrified using presently available technology. Data processing centres, consuming baseload, are being considered. A large part of data centre load is cooling load. It offers potential for flexibility delivered over short timeframes (including peak demand reduction) and also sector coupling possibilities as the excess heat is used in district heating systems. However, the technical potential for data centres to provide flexibility will be baked in at the time of investment; and flexibility value is currently low. Therefore, whereas overall demand volatility may increase due to electrification, price responsiveness in manufacturing will most probably be low, at least before 2030.

Electrification of the heat sector is well under way [16]. At present there are approximately 30 heat pumps installed according to Dansk Fjernvarme. Heat may be stored for seasonal storage in water reservoirs or in borehole thermal energy storages. There is a great potential for this in Denmark. The heat sector will be able to provide short-term flexibility by turning off both direct electric water heating and heat pumps. If heat storage capacity is increased, the heating may be turned off for longer time.

There is increased focus on the decarbonisation of the gas sector. In that context, a number of fundamental choices related to the role of gas have to be made, for example:

- Decarbonise fossil natural gas, with CCS?
- Convert the gas grid to another energy carrier (hydrogen?), or close/reuse parts of it?

The challenges for these decisions are:

- Geological structures, infrastructure and cost for underground deposition of gas
- Infrastructure and cost of gas reformation
- Properties of hydrogen as a pipeline energy carrier (reuse of infrastructure)
- Cost and scale of water electrolysis

[16] Installation of direct heating and large-scale heat pumps is done e.g. in Frederikshavn Forsyning and the demonstration project by HOFOR, CTR and VEKS in Copenhagen.

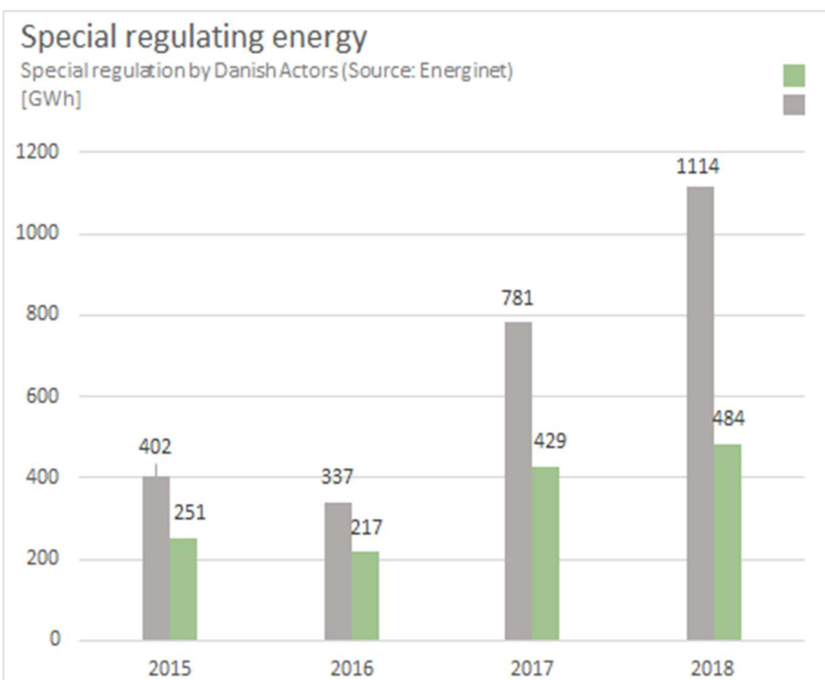
ANNEX E – LOCATIONAL REDISPATCH

One form of locational scarcity reflected in today's Danish market arises in the form of a re-dispatch market, which is activated in intraday timeframes. The objective is to reduce output from Danish wind at times of high wind to limit North-South flows within Germany. The arrangement stems from an obligation placed by the European Commission on Germany to offer to the day-ahead market a minimum amount of capacity on the Danish-German border, which cannot be physically accommodated. The required amount offered for cross border access to Germany will increase further (to 1100MW, from 1000MW today) until 2020.

To deliver the reduction in flows to levels which can physically be met, Denmark has in recent years seen an increase in Special regulating energy (down-regulation) mainly delivered through reduction in operating wind power capacity. Figure 3 shows up-and-down regulation from 2015-2018, where it is seen that there has been an increase in down-regulation of 35% from 2015-2018.

Figure 6 – Development of special regulation

Up-regulation
Down-regulation



Source: Energinet

In 2019, this has Year to Date (Nov. 6, 2019) amounted to 1122 GWh of down regulation, corresponding to 3.2% of the Danish electricity consumption. In relative numbers the YTD numbers from 2019 are larger than the 1114 GWh which was down regulated for the full year 2018.

A more effective outcome would be if redispatch arrangements could be shared with other Nordic countries, allowing the down-regulation to be delivered by re-scheduling hydro production rather than curtailing Danish wind.

ANNEX F – TECHNOLOGIES TO MEET FUTURE FLEXIBILITY NEEDS

The nature of flexibility needs will change over time, and as synchronous generation decreases, new tools to manage frequency will be needed. Ireland is a smaller and less connected system than Denmark, but below are the ideas which we are discussing with EirGrid. To the extent that these technologies are needed, suitable prices and market arrangements will be needed to allow investments to be made.

Figure 7 – Technologies needed to resolve future flexibility challenges in low-inertia systems

Time frame	Challenge	Possible technology solutions
μs to s	**Control and non-fundamental frequency stability**, including: weak grid regulator stability; subsynchronous phenomena; high frequency oscillations	Synchronous reinforcement, new grid-following controls for IBR, grid-forming inverters (GFI), damping / filters
Cycles to 10s of seconds	**Fundamental frequency stability**, including: transient voltage collapse, loss of synchronism, excess RoCoF, fundamental frequency small signal instability	Flywheels, enhanced H synchronous condensers, high power kinetic storage, de-clutched turbines, GFI, synthetic inertia variants, AC interconnection
10s of cycles to tens of seconds	**Frequency containment**, including: delivering arresting power / FFR; avoiding UFLS; ineffective / counter-effective UFLS; inadequate / slow Primary Frequency Control **Low periodicity instability**, including: interarea oscillations	Various FFR resources, PMU based or augmented frequency controls, UFLS alternatives, adaptive RAS, high speed / fast response demand side technologies
10s of seconds to minutes	**Frequency restoration**, including: secondary control	PSH and variations, moderate speed demand side technologies, batteries, high energy kinetic energy storage
5 minutes to hours	**Real time balancing**, including: tertiary frequency control; wind and solar variability	Dispatchable and participatory demand side technologies, V2G, G2V, ramp forecasting, residential DSM

Hours to days	**Resource adequacy**, including: wind droughts; weather extremes	Thermal storage / load shifting, alternative fuels for fossil plants, emergency class DSM, extremes forecasting, residential DSM
Weeks to months to years	**Seasonal and intra-year resource adequacy**, including: seasonality of resources; annual variation of resources	Seasonal thermal, P2X, P2Fuel, massive ESI (industry / sector specific), residential DSM
Instant to hours	**System restoration**, including: black start; network energization; cold load pickup; degraded awareness; degraded controllability; reassembly of islanded, live microgrids; coordination with other sectors	Batteries and other mid to high energy storage technologies (with GFI), enhanced situational awareness, AI assisted restoration

ANNEX G – LITERATURE LIST

- Market Model 2.0 - Final Report, Energinet 2015
- Markedsmodel 2.0 - Teknisk Baggrundsrapport, Energinet 2015
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