2.4 Denmark: centralised versus decentralised renewable energy systems

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2.4.1 Introduction

In 2012 the Danish parliament voted by a large majority for Denmark to become 100 per cent renewable by 2050 (Klima- Energi og Bygningsministeriet 2012). This decision was the result of a conflict laden political energy transition process (Hvelplund 2013), which had been underway since the first oil crisis in 1973. It was, at the normative level, a Danish 'end of the beginning' of a transition from the fossil fuel era to an energy system based upon renewable energy technologies. The 2012 decision has been confirmed – again with a large majority – by the Danish parliament in an energy agreement dated 20th June 2018.

However, good intentions and political aims are not enough to meet this target. For the transition from fossil fuels to a system based on 100 per cent renewable energy and energy conservation to succeed, there must be a better understanding of the needed technical and institutional changes and its regulatory framework (Hvelplund & Sperling 2018).

The political process to deliver both the renewable energy capacity already in existence by 2012 and the later commitment to 100 per cent renewable energy generation did not flow smoothly. For development to proceed in the period 2018–2050, a number of areas must be addressed, including: development of new policies, the competition and conflicts between interest groups, and acceptance questions regarding new renewable energy projects.

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This ambitious goal for 100 per cent renewable energy by 2050, can only be reached with continued policy support for the development of both energy conservation measures to reduce consumption and the implementation and integration of renewable energy technologies that deliver a fluctuating supply (Hvelplund, Østergaard & Meyer 2017; Hvelplund & Djørup 2017; Mathiesen et al. 2015). Policies to deliver new renewable technologies, such as wind turbines, solar energy, and biomass energy (Ridjan et al. 2013), are, on their own, inadequate to enable the successful integration of an intermittent supply into the energy mix. However, despite recent governmental activity demonstrating a greater recognition and acceptance of such requirements inherent in this shift to renewables (Energinet.dk 2015), this has not been followed up with an accompanying shift to concrete policies to support the necessary inter-sector integration that is required (Hvelplund, Østergaard & Meyer 2017). In their place there is an unclear assumption that the increasing amounts of renewable energy sources can be managed by building additional electricity interconnectors from Denmark to Holland, the United Kingdom, Germany, etc. At the same time, the integration of the supply side and energy conservation measures have not yet been sufficiently dealt with (Energinet.dk 2016).

For the following discussion it is worthwhile realising that the paradigmatic character of the ongoing change is a transition from relatively scarce greenhouse gas emitting stored fossil fuels that can be used when needed, to clean and abundant renewable energy sources that are fluctuating, and have to be harvested, when the sun shines and the wind blows, and stored so that they can be used when needed. It is worth noting that the switch between these models of energy generation can be made more easily with the support of a small amount of biomass-based energy production (Connolly et al. 2013; Lund et al. 2011).

This country report focuses on the organisational consequences of such a transition from fossil fuels to mainly fluctuating renewable energy sources and increased energy conservation, and considers questions such as: can this change be managed within a centralised model where surplus wind power is exported to neighbouring countries through a network of power interconnectors, where wind power plants are mainly owned by the large former fossil fuel power companies; alternatively, should the transition rely on a decentralised model with smart energy systems and flexible energy consumption delivered by integrating heat, power, transportation, biomass, and energy conservation; furthermore, should this be organised by cooperatively owned wind power plants synchronising supply-side and energy conservation investments? These questions help shape the agenda of current development of the Danish energy system.

Before discussing the merits of decentralisation versus centralisation, we will analyse what can be learned from the energy transition that has already taken place from 1975 to the present, dividing this analysis into two phases from 1975 to 2000, and 2000 through to the present.

2.4.2 Phase 1: 1975 to 2000 – the development of efficient single renewable energy technologies

From the mid-1970s to around 2000, the main focus was on the development of cost efficient and well-functioning single renewable energy technologies such as biogas plants, wind turbines, solar heating technologies, etc. In this period, renewable energy only had a minor share of both heat and power production (Hvelplund 2013). The result was that wind power only produced around 3–5 per cent of total electricity consumption annually in the mid-1990s, and in windy periods, not more than 10 to 15 per cent. Wind power was a minor player on the field of energy generation, meaning that fossil fuel plants could continue with business as usual in the existing fossil fuel based infrastructure.

This first phase of development of modern renewable technologies began 45–60 years ago, with roots back to wind powered electricity in 1903 (Thorndahl 2009) and Poul La Cours experiments with hydrogen storage of energy by electrolysis in 1895 (Quistgaard 2009). Today, both photovoltaic and wind power can be produced at a similar cost per kWh to fossil fuel based electricity when external costs are excluded. In fact it is actually much cheaper to produce when external costs are included (Ea analyse 2014).

The development of the first phase is characterised by unstable policy developments with constant conflicts between a centralised model of development based upon the interests of the large fossil fuel-based companies and Danish Industry,[11] and a decentralised model of renewable energy development driven by NGOs,[12] skilled innovators developing new technologies, and small industrial companies (Kooij et al. 2018). It should be noted that this early developmental phase, in the 1970s and beginning of the 1980s, took place against the status quo of a centralised energy policy favoured by the majority of politicians and in the face of strong lobbying by the large power companies (Jensen 2003) and the Association of Danish Industries. These organisations regarded wind power and renewable energy as unrealistic and too expensive, opting instead for coal and nuclear based power production (Beuse et al. 2000; Christensen 1985).

However, in the latter part of this first phase, the share of wind powered electricity production grew to 13 per cent of total electricity consumption and wind turbines were made 'ready' for large-scale deployment with relatively large wind turbines of 2–3 MW. At the same time as these developments were taking place, Denmark saw the creation of around 400 flexible combined heat and power (CHP) systems based on biomass and natural gas, which due to their flexibility in producing energy, provided a more stable environment for integrating wind power, with its intermittent generation levels.

[11] The organisation of Danish industries.

[12] The organisation OOA, against nuclear power and OVE, For renewable energy, NOAH, an environmental organisation.

The development and implementation of technically and economically efficient single technologies did not happen automatically, but as a result of 20 to 30 years of technology developments since the mid-1970s, based on a combination of active, small and medium-sized industries, energy focused NGOs, and a democratic process that enabled the policy suggestions from these NGOs to be taken seriously by parliament and implemented despite resistance from the established fossil fuel based power companies (Kruse 1983; Faurby 1982; Hvelplund 1984; Beuse 2000).

One of the most important policies from the beginning of the 1980s was a type of[13] feed-in payment system for wind power sold to the public grid. Another very important policy was that shares in wind power should be local and distributed to many owners; a tax exemption was put in place for incomes from wind power production of less than 150 per cent of the owner's annual electricity consumption. Wind turbine owners were required to live within a 9 km radius from the turbine. In this phase wind power was locally owned (Gorroño-Albizu, Sperling & Djørup 2019), and in the mid-1980s there were between 120,000 and 140,000 local wind power shareholders.

Consequently, wind power gained a strong and widespread political base resulting in parliamentary support despite opposition from fossil fuel companies in the critical period 1987 to 1990, where a 40–80 MW/year home market was required for wind to survive. This was despite the post-1987 collapse of the, roughly 200 MW/year California market, and a situation with almost no world-market sales (Madsen 1988; Beuse et al. 2000).

In this period, Danish wind power survived on a fragile home market due to a continuation of parliamentary support and subsidies for wind power which may not have prevailed without the policy pressure exerted by energy NGOs and the more than 120,000 wind turbine shareholders.

In parallel with this development of wind power that took place up to the early 1990s was an ongoing debate regarding the introduction of small, mainly natural gas-based, CHP units to be established in existing consumer owned district heating systems in small cities. After a longer political dispute, and with resistance from the established power sector, rules were introduced that made these CHP units economical; approximately 400 units were built between 1990 and 1995 amounting to 1.8 GW or 25 per cent of total thermal power capacity. Over the same period, large coal fired power plants lost around 30 per cent of their market share.

What can we conclude from this first phase?

One thing to conclude is that transition takes time, especially when there is no real consensus regarding the direction of development. It took around 40 to

[13] To qualify, this was a price equal to the payment per kWh for a 20,000 kWh/year consumer in their respective Distribution System Operator region.

50 years – from 1974 to 2018 – to develop the current new generation of wind turbines. This development had its roots in the Danish wind power experiences dating back to around 1900 (Christensen 2013). Taking a longer-term perspective, one could say that this current generation of electricity generating wind turbines took 120 years to be realised, with a long fossil fuel period during which wind power development was paused, taking place from 1920 to 1967 or 1977.

From about 1980, when wind power again made its presence felt, development has been slow, but despite resistance from the fossil fuel based power companies, it has been a success. Possibly as a result of its low share of power production, wind power has been viewed as a relatively harmless technology by the members of a hostile fossil fuel-based power infrastructure.

Again, it is important to note that from this first phase of development, wind power and energy conservation in Denmark did not happen automatically but was, to a large extent, driven and developed by small industries and energy NGOs in a conflict-laden political process, often with persistent resistance from the large, established fossil fuel companies, and the Danish Association of Industries (Sønderriis 1998). It is important to emphasise that this development was the result of concrete policies implemented by the Danish parliament in liaison with the relevant actors in society that were, to a large extent, supported by organisations such as energy NGOs, with no vested interests in the old fossil fuel technologies, or in a process that could be described as an ‘innovative democratic process’ (Hvelplund 2013).

Denmark has a long and strong tradition for non-profit consumer and municipality ownership. This is also the case within the electricity infrastructure which, until 2004, was 100 per cent owned by municipalities and consumers. In 2004 the power plants were sold and subjected to market competition on the Scandinavian Nordpool market. The power plants were sold to the Swedish state-owned company, Vattenfall, and the Danish state-owned company DONG, and thus changed from consumer and municipality ownership to state ownership.

The natural monopoly distribution system operators (DSO) remained consumer and municipality-owned, and subject to a non-profit regulation regime, where energy companies generally do not have the right to use profits for purposes other than to lower consumer prices, although they do have the right to charge consumers for production costs. This could be called a double regulation that, by means of a combination of a non-profit regulation and consumer ownership, provides an incentive for low prices.

This regulation has lately been changed to a new type of double regulation where the non-profit regulation has been replaced by a cost ceiling benchmarking regulation (Hvelplund 2018).

As a result of popular allegiance to consumer and municipality ownership, proposed development of new energy plants in Denmark, especially wind power plants, engender consumer opposition if they are not consumer and/or locally owned. On the other hand, the association of Danish energy companies (Dansk Energy[14]) – a strong lobbying group – has members that include the large power companies Vattenfall and Ørsted (formerly DONG), which have a strong inclination towards Vattenfall and Ørsted ownership of the new electricity production technologies, especially wind power. This has created a situation of conflict within Denmark where the large power companies wish to own the new power production technologies, whilst consumers and those living close to wind power plants tend to accept new wind turbines only if they get a significant share in ownership (Warren & McFadyen 2010).

It is important to emphasise that the consumer ownership share of the value-added chain historically did not include fossil fuel extraction and transportation nor the value-added linked to production of power plants, power grids, etc. In reality the consumer ownership share of power production value added was only linked to the conversion part of a fossil fuel system and amounts to around 25 per cent of the total value-added chain (Hvelplund 2001). It is worth noting that the share of consumer ownership may potentially increase in future renewable based systems, if the fossil fuel share is replaced by a smart energy system consisting of renewable energy supply systems in combination with technologies for the integration of large shares of fluctuating energy.

Finally, it is important to be aware that a district heating infrastructure, covering around 60 per cent of the heat demand, has been successfully developed and implemented. This represents an important part of an infrastructure that potentially integrates both large amounts of fluctuating renewable energy and can embody high percentages of heat conservation and low temperature heat in district heating systems.

2.4.3 Phase 2: the need for an integration infrastructure

It is relatively easy to develop and implement new renewable energy technologies with intermittent supply if they only supply a small share of the energy demand and consumption, because a minor supply from these single technologies can be fitted into the existing energy infrastructure without fundamental changes in the socio-technical energy system.

It is more difficult both at the normative, cognitive, and regulative level to establish energy systems that can handle large shares of fluctuating renewable energy supply. As such, in the second phase of renewable energy development, it is necessary to deal with the development of an integrative energy system that can handle large amounts of intermittent renewable energy supply by means of, amongst other things, integration of power production and heat in district heating systems with heat pumps, solar heating, geothermal heating, etc.,

[14] An association made up mainly of electricity companies.

combined with heat storage systems. Such systems were already discussed 40 years ago, when the need for integrating heat and electricity was analysed and described (Illum 1982). In Denmark, the basic district heating infrastructure to facilitate this integration has, without having the future integration as its purpose, been developed since the 1930s. Furthermore, a renewed expansion of the district heating infrastructure was established at the start of the 1990s both in the large cities and as a part of the 400 decentralised cogeneration plants established between 1989 and 1995. This resulted in an increase of district heating by 40 per cent from 1990 to 2015 (Energistyrelsen 2016). However, there has not been a systematic integration of heat and electricity; heat storage and heat pumps have not been added to the system for example, mainly due to the very high taxes placed on the use of electricity for heat production.

Denmark is now in a phase where integrating heat and electricity is a must, as wind power is becoming the dominant supplier of electricity, necessitating policies for the establishment of an infrastructure that can handle the intermittency inherent within wind power generation. In this phase the question is not any longer, whether a single wind turbine, biomass plant, or photovoltaic unit can produce electricity cheaper than a fossil fuel plant. This is an often used, but wrong comparison. Denmark is in a situation where a 50 to 80 per cent share of energy is supplied by intermittent renewable sources that cannot be compared to single energy supply technologies. Instead, the comparison is between different energy systems that can supply energy when needed, in the right amounts and quantities. This means that we must compare the economics of fossil fuel energy systems with renewable energy-based energy systems, which has been done by Mathiesen et al (2015) and Lund (2014 amongst others. Their work shows that a renewable energy system can be cheaper than a fossil fuel-based energy system, and can deliver energy in the right amounts, at the right time and in the right quality.

But are we establishing the needed infrastructure for the integration of the fluctuating wind power?

In 2015 Danish wind power produced 42 per cent of total electricity consumed, and more electricity in 600 hours of the year than the Danish total electricity consumption during these hours. This is expected to increase to 1400 hours per year in 2020, and already, wind power is exported to countries around Denmark at continuously reduced prices (Hvelplund & Djørup 2017; Bach 2017). At the same time wind powers close to zero short term marginal costs, outcompetes the CHP power production on the Nordpool market, and thus reduces the full-time production hours at both the large and the many small CHP systems, undermining the economic case for these types of production. This is a serious issue, as small CHP systems are likely to become an important part of a flexible infrastructure by supplying electricity in periods where there is only a little wind. Furthermore, the cogeneration plants are to some extent being replaced by inflexible biomass-based district heating systems in the small and large cities of Aarhus and Copenhagen for example, with CHP systems that generate a rather inflexible power supply. Thus, there is an ongoing development towards biomass-based district heating that limits the potential of integrating heat and wind power by reducing the size of the heat market that can be supplied with the less stable supply available from wind power in combination with heat storage and heat pumps. This is caused by an almost zero taxation on biomass for heat, and a high taxation, around €0.05 per kWh, on wind power for heat.

This development regrettably is occurring at the same time as the need to integrate the increasing shares of wind power in a socially and economically efficient way is being highlighted. This is due to the merit order effect (Hvelplund, Möller & Sperling 2013) that has resulted in continuously reduced wind power prices on the Nordpool market (Sorknæs, Djørup, Lund & Thellufsen 2019). Prices went down from around €0.04 per kWh to around €0.03per kWh in the period 2005 to 2015 (Hvelplund & Djørup 2017). This process of reduced wind power prices may continue in the future with plans for a 50 per cent to 60 per cent share of wind powered electricity consumption which could undermine the economics of wind power to an extent that, unless the market is reconstructed, will hamper further wind power expansion (Djørup, Thellufsen & Sorknæs 2018).

The hitherto reason behind district heating has been its fossil fuel efficiency caused by co-production of heat and electricity in cogeneration plants. This reason will be excluded in the future, as a large majority in the parliament in 2012 decided to phase out fossil fuels from the heat and electricity production.

In tandem with this fossil fuel phase out, a set of new argument for a renewable energy-based district heating is developing.

As hot water storage is cheaper by a factor of 100 per MWh for large heating systems compared to electric battery storage systems (Lund et al. 2016), hot water storage for heat at this stage of development are a first step towards handling an increasing share of wind power (with its intermittent supply), for use within the heat market. Hot water storage systems cost approximately €24,000/MWh stored for single houses, and between €500 and €2,500/MWh stored in the larger repositories in a city with district heating, it is a cheaper by a factor of 10–50, to store intermittent energy in district heating systems than in single house systems (Lund et al. 2016).

In cities it is therefore in 100 per cent renewable energy systems more economical to have district, instead of single house, heating systems. Also, for district heating systems, it pays to have low temperature systems because of the increased efficiency in the heat pumps and the reduced loss in the district heating network. Therefore, the system for integrating fluctuating wind power in Denmark is a low temperature district heating system in combination with heat pumps, and hot water storage systems. Furthermore, it should be noted that district heat pipes of good quality have a technical lifetime of around 50 to 70 years.

Along with this development on the energy supply side, it is important to note that in the envisioned 100 per cent renewable energy system of 2050, heat conservation of around 40 per cent compared to current heat use per m2 appears economically optimal (Lund et al. 2016). In transition from a fossil fuel system to a renewable energy system it is becoming technically and economically increasingly important to synchronise supply and demand. Firstly, because Denmark is currently in a transition process characterised by active investors on the supply side and much less active investors in energy conservation on the demand side: this is a serious problem that must be resolved. Secondly, because heat conservation must be implemented 'in time' to avoid costly overinvestments in the new renewable energy-based supply system for an uninsulated heat market. Thirdly, because the temperature in district heating systems should be lowered to 50-60 degrees celcius, as low temperature heat supply increases the efficiency of heat pumps (ie. the Coefficient of Performance (COP)), and of solar heating, geothermal heating, and low temperature heat from industries. This reduction in temperature can be implemented without having to invest in larger district heating pipes, if the heat consumption is reduced by heat conservation. This means that Denmark is now in an era where the synchronisation of investments in heat supply systems and energy conservation is increasing in importance.

What can we conclude from the second phase?

The rationale or justification for district heating is changing from being based on *energy efficiency in a fossil fuel-based cogeneration system* to being based on technology *that can handle both an increased share of fluctuating renewable energy*, and the implementation and use of a variety of renewable energy-based fuels (Lund et al. 2014).

It is important not to forget that this ability on the supply side should be underpinned by a systematic technical and organisational synchronisation of investments in the heat supply and heat conservation sides. Heat conservation should also further both low temperature systems that increase the efficiency of heat pumps and the use of industrial waste heat and be implemented in time to avoid overinvestments in supply side systems. This establishment of a new rational base for district heating may also help wind power from an ongoing steady fall in electricity prices resulting from the merit order effect (Hvelplund, Möller & Sperling 2013).

The first step in creating a rational economic basis for wind power is to increase its market size by integrating electricity and heat and thereby enabling wind to enter the heat market. Later steps should be taken to integrate electric based transportation and establish wind to fuel systems (Ridjan et al. 2016;Lund & Kempton 2008; Mathiesen et al. 2015). In this way, by integrating wind power into a smart energy system, the economics of wind may improve to a level where it escapes falling prices created by the merit order effect, meaning that it may pay to build the needed wind power capacity to deliver the 100 per cent renewables by 2050 scenario. However, this can only happen with a taxation policy where taxes on wind power for heat are set at the same level, or lower, than taxes on the scarce resource, biomass for heat. This is not in place today, where tax on wind electricity is high in comparison to the levy of zero tax on biomass for heat.

2.4.4 Decentralised smart energy systems versus centralised power transmission line scenarios

In this second phase of the transition to renewable energy, we have arrived at a crossroads where we are confronted with a choice between a mainly centralised development with large transmission lines and wind power plants owned by large power companies, or a decentralised smart energy system (Lund 2014) development with integration of heat and electricity, electric cars, etc., supported by local and regional ownership.

What follows, is a discussion of these divergent second phase strategies.

The decentralised integration paradigm: development of a smart energy system

When analysing the centralisation versus decentralisation question, it is useful to make an adequate description of the techno-economic character of a smart energy system.

Fossil fuels are stored energy that can be used when needed, however, the investment and management of the extraction of stored fossil fuel energy is only a possibility for large energy companies, *and therefore is an inherently centralised technology.*

The nature of renewable energy is that it is an intermittent source and must therefore be harvested when available. This necessitates the existence of an integrated infrastructure that can either store the energy for later use or transport it by means of interconnectors to other regions or countries where there is an energy need.

In a decentralised smart energy system (Lund et al. 2012), the storage feature of fossil fuels is replaced by coordination and integration technologies and facilities in smart energy systems.

Instead of a distant fossil fuel supply chain with extraction, transportation, and refining located far away from consumers, a smart energy system is established with investments in district heating systems, heat pumps, solar panels, heat storage, energy conservation, electric cars, wind to fuel systems, etc. This means that a value-added share in coordinated and integrated technologies based closer to consumers, replaces a relatively distant fossil fuel based value-added chain.

Consequently, smart energy system technologies may inherently be more suitable for decentralised socio-technical solutions than the fossil fuel-based system it replaces.

The question then, is what characterises the organisational and economic requirements linked to the development and implementation of smart energy systems?

First, smart energy systems need a multifaceted governance system that furthers investments in, and management of, integration technologies. As such, investments in district heating, heat storage systems (Ridjan et al. 2013), heat pumps, and solar heating should be structured in such a way that they can cope with intermittent renewable energy technologies, and must be combined with 'in time' investments in energy conservation. In later stages, the establishment of infrastructure for electric vehicles, wind to fuel systems, geothermal energy etc., will be needed.

The development and implementation of a smart energy system also requires coordination and collaboration between owners of wind turbines, the TSO (Transmission Supply Operator), district heating companies, power distribution companies, and the municipalities and central legislative authorities. This coordination is much more multifaceted than 'just to' develop cost efficient renewable energy single technologies, and requires new organisational models that can develop, implement, coordinate, and manage these many transaction activities, both with regard to long-term investments and day-to-day management. This presents a complex and potentially difficult task of coordination, possibly from a distance.

Due to proximity to consumers it is reasonable to presuppose that the complex coordination and integration involved in smart energy systems, both at the investment and the operation and management levels, may have lower transaction costs in a decentralised than in a centralised governance model (Hvelplund & Djørup 2019). This hypothesis is supported by both transaction cost theory in the Coaseian tradition (Coase 1937; Coase 1988) and the epistemological arguments against central planning in the Austrian tradition (Hayek 1937; Hayek 1945). As coordination becomes more complex, it becomes increasingly costly to convey the adequate level of information to a distant central planning agency – whether industry or government.

Large companies may find themselves, as a result of the following, hamstrung by relatively high transactions costs in any transition to smart energy system solutions. This is due to, amongst other reasons, the fact that they would have to:

- Buy the local consumer and municipality owned district heating systems, which would be very difficult, as these companies are municipality or consumer owned and governed by a non-profit or consumer profit regime. Consumer profit means that any company surplus must be paid back to the consumers in the form of lower prices.
- Invest in heat pumps and heat storage systems linked to district heating systems owned by municipalities and consumers, or to make sure that these investments are implemented.

- Develop a multitude of coordination activities such as, dimensioning investments in the different technologies so that they supplement each other's, and concurrently establish the right amount of energy conservation 'in time' with a conservation level that supports the right low temperature district heating systems. Activities that all seem much easier to perform when the owners of the smart energy system components are the same heat consumers that should also implement the heat conservation investments.
- Distant ownership of onshore wind power is difficult in Denmark, as local citizens due to a long historical tradition, want influence upon such plants by means of, for example, a large ownership share.
- Handle politically conflict-laden negotiations between distant potential owners like the Swedish power company Vattenfall, paying no local taxes and supplying no profits to local actors. The local inhabitants of such distant owner models tend to experience the noise and visual disadvantages of energy generation without receiving benefits from the projects. One ongoing case is the conflict between the Swedish state owned power company Vattenfall and the local Nørrekær Enge wind power community (Olsen & Christiansen 2016).

Due to complicated regulations and the requirements in terms of communication, large distant power companies may struggle to design appropriate investment schemes and to operate these in an efficient way in accordance with local wishes, capabilities, and technological conditions. These companies do not have ownership or control of the smart energy system technologies, nor the ability to handle large amounts of information, in order to behave in a strategic and tactically efficient way. They therefore are comparatively hindered as actors in a decentralised smart energy system.

Consequently, from a political economy point of view, large energy companies may tend to support other more centralised solutions, where their comparative advantages are stronger. Such centralised scenarios will be discussed in the next section.

The centralised on- and offshore wind and transmission line solution

Established power companies, or other distant owners, appear then to face difficulties in implementing and managing smart energy system integration infrastructure. At the same time, these companies and their associations, Danish Energy for example, systematically advocate for 'solutions' that are within the reach of their members within the electricity sector (Energinet.dk 2014). Such 'solutions' mainly consist of offshore wind power in combination with large power transmission grids, which are seen as a way of geographically 'sending surplus wind power to another place' and receiving needed capacity from other countries as reserve power in periods with too little wind power. In Denmark this is combined with large inflexible biomass cogeneration plants that behave almost in the same way as coal fired power plants in the larger cities of Copenhagen and Aarhus. These types of solutions are supported by the Danish TSO, (Energinet.dk 2016), where priority is given to the development of transmission lines between countries. If there is 'too much wind power' in Denmark, it is exported to Germany, the Netherlands, or Scandinavia. When there is too little wind power compared to consumption, additional capacity is imported from neighbouring countries. This is the model in Denmark today, and it is also the model at present proposed for the future, as supported by the TSO, Energinet.dk. Denmark is therefore building, and planning to build, transmission lines to its neighbouring countries without first examining the possibilities and the economics of establishing a smart energy system with a local and regional cross-sectoral integration infrastructure. In practice local and regional cross-sectoral integration is, in the scenarios of the Danish TSO and of the association of Danish power companies (Danish Energy), a second priority.

At present, a centralised transmission line model is favoured by TSOs at both European and Danish levels (Energinet.dk 2017). As suggested, this has already resulted in building large transmission lines to the Netherlands; the COBRA cable received a subsidy of €85.5 million out of a €700 million investment and plans exist to build the Viking cable to the United Kingdom (Djørup 2016; Energinet.dk 2016) which will also receive EU subsidies. The main solution in Denmark today, is this centralised and transmission line model. However, the Danish TSO has also argued for a 'we do both' model, which would mean supporting both the local and regional integration smart energy system model *and* the transmission line model. Sadly, in reality, the smart energy system model is not supported, and in Energinet.dk background reports it is assumed that only around 5 per cent of the heat market will be integrated in 2020 and 15 per cent in 2035 (Energinet.dk 2016), when in fact three times as much would be possible. Meanwhile this centralised transmission line model does not seem to solve the renewable energy intermittency challenge on a long-term basis. With increasing shares of such intermittent renewable energy, Denmark's neighbours are also increasing their wind power capacities and the Danish wind regime is similar in the North European countries (Bach 2017). So far the cost-benefit analysis made by the TSO, and justifying investments in transmission lines has been questioned as not being transparent and disregarding alternative courses of action (Djørup 2016; Lund et al. 2017; Mathiesen, Lund & Djørup 2018). The above analysis indicates that the solution lies in smart energy systems with more flexible electricity consumption delivered by means of local and regional integration of heat, electricity, transportation, wind to gas, etc. (Lund et al. 2012; Mathiesen et al. 2015; Bach 2017).

Solutions that integrate increasing amounts of intermittent renewable energy in a smart energy system are needed and are already supported by thorough calculations showing that it is possible and cheaper to develop and implement a decentralised model, where surplus wind power is integrated into the heat and transportation market (Lund et al. 2012).

2.4.5 Conclusion and policy recommendations

The above discussion of the first phase of renewable energy development has shown that a technological transition takes time and that it does not happen on its own. A sort of innovative democracy is necessary, where the influence from new NGOs independent of the old fossil fuel-based companies is needed. It also demonstrated that the development of single renewable energy technologies is 'easy' in the way that these could be absorbed into the old fossil fuel infrastructures without major changes to these, due to the very minor share of total electricity supply that these single technologies contribute.

In the second phase of renewable energy development, where wind power produces more than 40 per cent of electricity production, the basic infrastructure has to be changed, to absorb large amounts of intermittent energy. As with the changes in phase one, such changes do not happen unilaterally in the inherited market arrangements. Concrete policies are necessary to bring this change about.

The viability of decentralised smart energy system models has been theoretically well documented for decades and practiced to some extent by a few district heating companies. In comparison, the model supporting large heat pumps and large heat storage systems based on wind power is in a start-up phase with only a few projects, and as such, it has not yet reached a full-scale implementation.

A decentralised smart energy system model seems to be able to solve the problems linked to a transition to intermittent renewable energy sources, but under present policies has not been fully realised. The present high tax on wind power for heat and zero tax on biomass for example, mitigates against such a transition.

On the contrary there still is a strong tendency towards realisation of the centralised offshore transmission line scenario in combination with distant ownership of wind power plants and biomass heat based on imported biomass in the largest cities. Furthermore, this development is still subsidised, and in upcoming years, several billion Euros will be invested in interconnectors, despite there being little evidence that this model will solve the problem of integrating increasing shares of intermittent wind power, either technically or economically. Technically because Denmark's neighbouring countries are expanding their wind power capacity and have similar wind regimes, and economically because it relies upon huge EU subsidies and might not be able to compete with smart energy system solutions on an economically equal playing field.

So, it looks as if Denmark and the European Union are in a situation where billions of Euros will be invested in a centralised model that will prove to be a blind alley, incapable of integrating increasing amounts of intermittent energy, and at the same time hindering the development and implementation of a decentralised model that does have the ability to solve the problem of intermittency. It is therefore necessary, to level the playing field to make it possible to establish the new smart energy system infrastructure.

This could be achieved by introducing the following policies:

- An EU directive that introduces a subsidiarity principle where local integration via smart energy systems has priority and, if needed, investments in transmission lines take second priority.
- The European Union should give the same level of subsidies to a decentralised smart energy system infrastructure, as the present EU subsidy provides to transmission interconnectors.
- Denmark's taxes on wind power for heat should be set to at least the same level as taxes on biomass.
- Renewable energy tenders should be designed so that it is possible for local citizens to participate as a foundation, where the profit goes to both local citizens and to the common good of the region.
- Introduce legislation whereby wind power project managers are compelled to sell at least 51 per cent of a wind power project to local consumers, municipalities and local companies; that this local ownership percentage should be kept during the lifetime of a renewable energy project.
- Allocate 30 per cent of the surplus from a wind power project to a foundation with the deed to use the money for the common good. This could be for environmental purposes and for the development of smart energy system integration technologies. It could also be used to support energy conservation in the region.
- Introduce changes to the role of the Danish TSO, Energinet.dk, so that it is obliged to support integration of intermittent renewable energy in accordance with a subsidiarity principle.
- Introduce transmission tariffs, where the payment is a function of consumer use of the transmission system. Payments are currently charged only for transmission in situations of bottleneck limitations in the transmission line.

The implementation of a decentralised smart energy system-based integration of renewable energy could become a realistic possibility if the above policies were introduced at both the EU, and the national level, in Denmark.

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