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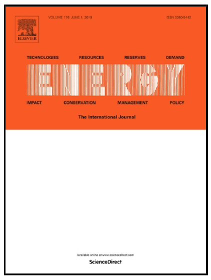

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Abstract

In a transition to 100% renewable energy, public regulation has to deal with, among other issues, price efficiency, security of supply, and the transition from sector based fossil fuel systems to sector integrated smart energy systems based on energy conservation and renewable energy. Most studies and practical policies only focus on building "green incentives" into the money flows. There is less research focus on the importance of citizen and consumer ownership models in the green energy transition process. This is problematic, as different ownership models have different influences on price efficiency as well as the ability of the smart energy system to integrate large amounts of fluctuating energy. The purpose of this paper is to analyze citizen and consumer ownership models both with regard to their influence on consumer prices and their capability to handle the multitude of coordination tasks in a transition from sector based to integrated smart energy systems. A consumer ownership model has positive potentials both in terms of maintaining low energy prices and securing low coordination transaction costs in smart energy systems. The realization of these positive potentials is dependent on the concrete institutional context and public regulation in which a given ownership construction is embedded.

1. Introduction

A first mover transition from a fossil fuel based to a renewable energy based system involving energy conservation requires an energy organization generating low energy prices and giving economic space for the "premature" introduction of new technologies. As a second requirement, the organization must keep transaction costs low, when coping with the multitude of coordination tasks in a smart energy system integrating large amounts of fluctuating renewable energy.

In the period from 1976 and onwards a Danish governmental energy policy was developed that gradually increased the support to the development and implementation of renewable energy and energy conservation. This policy was, after the 1973 energy crisis amongst others based on a public debate between the ministry of energy and proponents for the official 1976 energy plan [1] and supporters of an 1976 alternative energy plan [2]. The adherents of the alternative energy plan argued that a scenario without nuclear energy was a realistic option. In the following years several other official and alternative energy plans were important contributions to the energy policy discourse. For instance: In 1981 the Ministry of Energy published an energy plan that included nuclear energy[3], in 1983 a group of researchers from different Danish universities made an alternative energy plan focusing on energy conservation and Renewable Energy[4], in 2012 a group of researchers presented a plan with 100% Renewable Energy before 2050 [5], and in 2015 the Danish association of engineers published an energy plan with 100% Renewable Energy in 2050 [6].

Internationally, Denmark has, since around 1976, been a first mover within wind power, cogeneration of heat and electricity, biomass based energy as well as within the energy conservation area. This position was achieved through a set of policy reforms including subsidies to investment in wind turbines, a sort of feed-in payment for wind power since the mid-1980s, 30%-50% subsidy to energy conservation investments, extensive renewable energy research programs and subsidies to renewable energy pilot projects. Most of the measures that made Denmark a first mover was, and still is, based on an active policy that has required financial support, either from the state budget or directly via surcharges on the electricity prices. New renewable energy technologies were massively introduced in a technological learning process before they were fully developed, and thus before they had reached the low cost levels of mature technologies. Historically, the extra cost of this first mover technological learning process has been a recurrent theme for political discussion [7] regarding to which degree an early support to the new renewable energy technologies is hampering Danish international competitiveness. In this policy discourse, the proponents for a continuation of support for new renewable energy technologies were helped by the fact that the Danish electricity prices *including subsidies* to the new renewable energy technologies were substantially lower than average EU electricity prices for industry. Arguments such as; "our industry cannot compete internationally due to high prices induced by subsidies to renewable energy" were weakened simply because Danish electricity prices for industry remained lower than the EU average. Consequently, there are good reasons to believe that the low Danish electricity prices including subsidies for renewable energy have made space for the extra costs of a first mover introducing the new renewable energy technologies years before they reached technological and economic maturity. And thus also for the establishment of a technological learning process that has made Denmark a leader within a set of renewable energy technologies.

Since around 2000, the Danish renewable energy development has been in a “take off” process regarding the share of renewable energy in the Danish energy system. In 2017, wind power production equaled 40 percent of the electricity consumption, with governmental plans for 50 percent in 2020. Consequently, there are now an increasing number of hours per year in which the wind power production exceeds Danish electricity consumption and wind power is exported at constantly falling prices creating economic problems to wind power projects [8]. This price trend might be counteracted by means of new ownership and power exchange constructions in smart energy systems. The transition to renewable energies therefore has reached a new phase, where the local and regional integration of fluctuating renewable energy into smart energy systems is becoming increasingly important [9]. The policies for this integration were discussed in [10], underlining the needs for lowering the taxes on electricity for heat. The value of integration of heat and electricity for wind power economy was discussed in [11]. Simultaneously, the development and implementation of new integration policies regarding ownership, public regulation, energy taxation, tariffs, subsidies, etc. for this transition to smart energy systems have become more and more essential [12].

In a first mover transition to 100% renewable energy, the above discussion leads to two critical problem areas:

- How to organize a low energy price base that can “pay for” the extra costs of a first mover “premature” introduction of costly new energy technologies.

- How to develop an organization that minimizes the transaction costs linked to the multitude of hour to hour and investment coordination tasks in a transition from sector based to integrated smart energy systems.

It is, as a response to these two problem areas, the aim of this paper to analyze two interrelated aspects of consumer and citizen owned energy systems:

Firstly it is analyzed to which extent and in which way the Danish governance structure consisting of consumer and municipality ownership in combination with a nonprofit public regulation regime has resulted in low electricity prices.

Secondly a preliminary analysis is conducted regarding the transaction cost attributes of consumer and citizen ownership organizations with regard to their coordination of the multitude of hour-by-hour operations and investments in the different components of integrated smart energy systems.

There are many articles dealing with consumer participation and renewable energy projects. In [13] the question of compensation payment to project neighbors is discussed, in [14] the institutional conditions for wind power cooperatives in different countries are compared, in [15] the interrelationship between governance at the central and the decentral level is analyzed, in [16] a model for the institutional preconditions for community energy projects is analyzed. Only rather few are dealing systematically with the consumer ownership theme. In [17] the question of consumer cooperatives and large near shore wind power projects are dealt with, and the conclusion is that present tender rules are hampering the development of large consumer owned energy companies. In [18] consumer ownership is placed in a larger institutional context and the conclusion is that consumer ownership will not, due to the strong power influence from existing energy companies, develop without a new institutional conditions supported by the parliamentary political system. Meanwhile very few articles are deals with cooperative ownership and economic efficiency, , where [19] analyzes production cooperatives that are not natural monopolies, or [20] analyzes consumer cooperatives, but not natural monopoly consumer cooperatives. There does not seem to be articles that deals with price efficiency of consumer owned natural monopolies. This statement is supported by another article; "The case of the missing organizations: Cooperative and textbooks" where it is shown that there are almost not texts in general economic textbook chapters dealing with cooperatives and the area of operation, where they might be organizational and economically beneficial[21].

The investigated literature furthermore does not systematically deal with the typical Danish governance system consisting of a combination of consumer ownership and nonprofit public regulation. Therefore the question in this paper, whether consumer ownership of natural monopolies in cooperation with the right public regulation results in low energy prices is landing on a white spot in the landscape of economic theory. Furthermore, when dealing with the regulation of natural monopolies, there does not seem to be any focus upon whether consumer ownership has any effect upon the regulation efficiency, as discussed in figure 3 in this article[22].

Regarding the second question in this paper, it has not been possible to find literature that deals with the relationship between ownership and transaction cost caused by the multitude of coordination activities needed in a transition to renewable energy based smart energy systems.

This analysis should not be limited to the theme of consumer ownership in combination with nonprofit public regulation. The study should also include a description of the fundamental technological attributes of the electricity system to be governed, considering its often high degree of natural monopoly characteristics in the value-added chain. An in-depth analysis of the economic properties of the present fossil fuel system, the coming renewable energy and energy conservation energy system, and the coordination tasks linked to this transition is therefore needed.

This analysis requires that the goals of an electricity system are stated, and that it is clarified what is meant by an electricity system, and how we define consumer, citizen and municipality ownership and embedment in a governance system.

2. Theoretical approach and methodology

The theoretical approach in this article has the following characteristics:

It includes a systematic description of the value-added chain in an electricity system in transition. This is considered important, as a transition to a smart energy system brings the main part of the value-added chain closer to the consumer. It also is important to know how large a share of the energy production that is consumer owned, when analyzing the cost effects of ownership.

The theoretical approach also includes a description of our perception of the different elements of regulation power in a natural monopoly at the energy scene. In connection to this, we regard a description of the ownership construction as important to the understanding of the behavior of a natural monopoly. We have also found it of importance to describe the links between ownership and regulation and the concrete elements that have to be coordinated in a future smart energy system.

The methodology in the price comparisons is to study:

- The energy price incentives built into the present governance system.
- The general price statistics.

- A concrete price comparison of the consumer owned KONSTANT and the external shareholder owned RADIUS.

In the preliminary analysis of transaction costs linked to the coordination tasks in a smart energy system, the concrete coordination tasks are discussed in relation to the position of local district heating consumers.

3. The value-added DNA in a fossil fuel based electricity system?

Electricity supply systems cannot be understood as identical “dots”, reacting in the same way upon specific regulatory measures. Electricity supply systems (ESS) are different from country to country and period to period and therefore also react differently upon specific regulatory measures. This is especially the case in a change from fossil fuel based to renewable energy based systems, as we will see in the following. In relation to this, it is important to analyse this difference as a function of different cost and value-added structures in both the old fossil fuel system, the systems in transition to renewable energy, and the phase with 100% renewable energy [23].

3.1. Value added in a fossil fuel based electricity supply system (ESS)

In figure 1, we deal with an electricity *service* supply system, by which we mean a system that buys supply services such as cooling, heating, movements etc., and not just electricity.

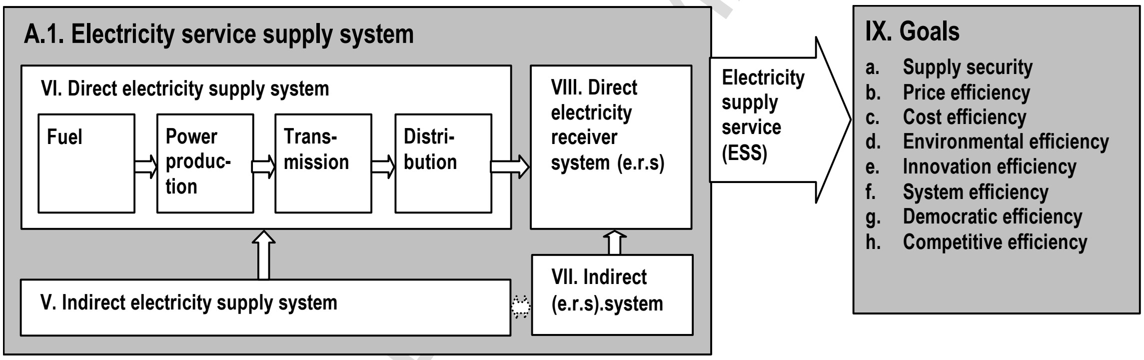

Figure 1. The direct and indirect Electricity Supply Service system.

Reference:[23]

From a governance point of view, it important to divide the electricity supply system into *the indirect* and the *direct* electricity supply systems.
The *indirect electricity supply system* is here defined as the energy supply side capital investment in power plants grid investments, etc.
The *direct electricity* supply system is defined as the activities in the electricity supply sector after having bought the power plants and the transmission and distribution lines.
In a period of fundamental change from fossil fuel to renewable energy, there is a considerable change in the share of the value added from the direct to the indirect electricity supply system. This change in the value-added distribution from the direct to the indirect ESS has, as we shall see later, profound impacts on the needed governance system.

In figure 1, we show an electricity *service* supply system ESSS in order to underline that we, in this article, do not include the electricity receiver part, but only the electricity supply system as shown in figure 2.

3.1. The value-added chain of a fossil fuel based electricity supply system.

The question is: Which are the general value-added characteristics of the fossil fuel based electricity supply system, which at present serves around 40 percent of the world's electricity markets? Answering this question is crucial, as this system, to a large extent, is supposed to be replaced with renewable energy and energy conservation systems within the next 20 to 40 years. And which parts of the value added was consumer owned in the fossil fuel based energy supply system? Figure 2 illustrates the value-added flow in a typical coal based fossil fuel system, as it was in Denmark in the late-nineties and still to some extent is. The numbers are based on a large coal fired power plant with a load factor of 5,000 hours.

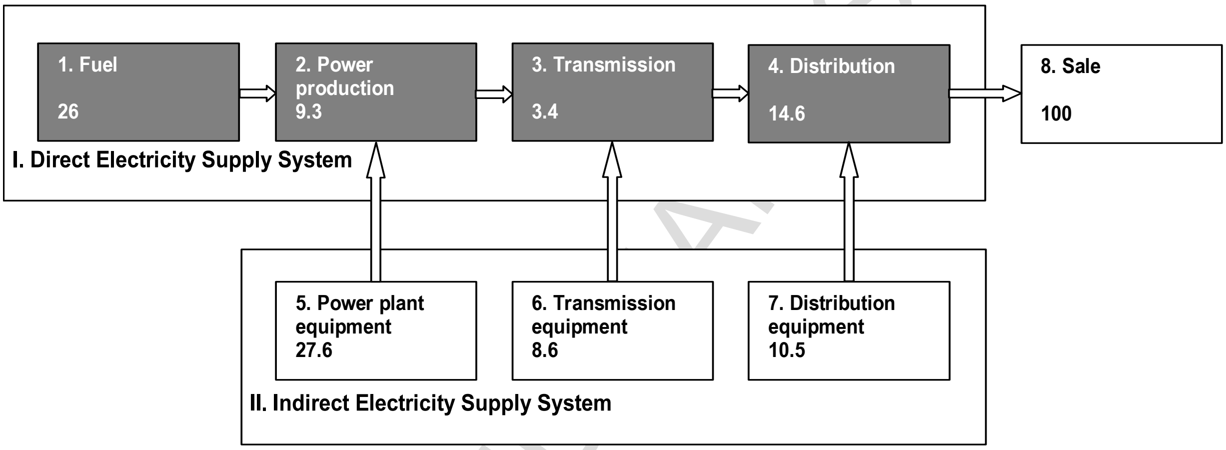

Figure 2. The value-added distribution in a coal based electricity supply system.

Reference: [23]

Figure 2 deals with a system which, to a very large extent, will be replaced with energy conservation and renewable energy systems within the next 20-40 years.
In this fossil fuel electricity supply system, electricity is delivered to the consumer at 100 value units (100 DKK, for example). It can be seen that out of 100 DKK, 53.3 DKK is paid to the direct electricity supply system as a whole, with 26 DKK disbursed for coal, 9.3 DKK paid to the employees at the power plants, 3.4 rewarded to the employees of the transmission system and 14.6 paid to the employees of the distribution system. Thus, out of 100 DKK paid for electricity, a total of **27.3** DKK is paid to the Danish employees in the direct electricity supply system.
In 2004, the power plants were "liberalized" and the natural monopolies, such as the distribution and transmission networks, in general remained public and consumer owned. But what did liberalization mean for the electricity system? Which parts of the value added in this system were liberalized?

First of all, the *indirect electricity* system, which from the point of view of the electricity companies represents the fixed cost, is still after liberalization bought from equipment producers. These are, as a general rule, private companies subdued to international competition. The liberalization of the Danish electricity system therefore did not encompass this around 50% *indirect electricity* share of

the fossil fuel ESS value added (fig.2).
In the Danish case, the power companies represented around 36.9 percent of the value added built into the electricity prices as seen in figure 2 (box 2+ box 5). Out of this, 26.3 percent was allocated to power plant capital costs, or the indirect ESS, and already privatised and subdued to competition. Consequently, the Danish 2004 liberalization reforms were in reality limited to the power production share in the direct electricity supply system, or in this case, only 9.3% of the value added in the Danish electricity supply system (ESS). This share was then privatized by being sold to the two state owned companies, Swedish Vattenfall and Danish DONG.

Before the 2004 liberalization, the consumer ownership share was 27.3 percent of the value added (2+3+4 in Figure 2). These 27.3 percent naturally had special importance, as they represented the decision power that determined where and whether to buy coal and other fossil fuels, and also whether to buy coal fired power plants or to rely on other power production units.
After the 2004 liberalization, the consumer owned share of the system was reduced to the natural monopoly Distribution System Operator (DSO) share of 14.6 percent of the value added.

The way in which ownership is organised in the ESS has a distinctive influence on both the energy prices and the transition process from fossil fuel based systems to renewable energy and energy conservation based energy systems. In the following, we will discuss the role of consumer ownership as embedded in the Danish governance system.

4. Consumer ownership and the transition from fossil fuels to renewable energy.

The main aim of this section is to determine which role the consumer and municipality owned Danish distribution system operators (DSOs) play both in relation to the prices and in a transition to renewable energy and energy conservation.

Firstly: Does consumer and municipality ownership give low prices that facilitate economically competitive financing of the transition to renewable energy systems?

Secondly: Are the consumer and municipality owned DSOs able to actively participate in the transition to renewable energy?

The distribution (DSOs) networks are natural monopolies and cannot be regulated at a market with different suppliers, as there is only one grid supplier available for the single consumer. Therefore, they must in general be regulated in other ways than through price competition.

We here define the purposes of governing an electricity system as to secure a stable electricity supply, low consumer prices and partly to ensure that social, socio-economic and environmental goals are successfully pursued.

4.1. Does consumer and municipality ownership give low prices that facilitate economically competitive financing of the transition to renewable energy systems?

The governance of the electricity systems can be divided into four consumer power areas: (1) ownership power, (2) buying power at the market, (3) state regulative power, and (4) last, but not least, and often forgotten, that these different powers are executed in an open and competent communication process. The character and quality of the communication are crucial to the optimal function of the governance system.

But how should the governance balance between these 4 dimensions of consumer power be designed in a natural monopoly system linked to the DSO value-added share of around 15% of the electricity price?

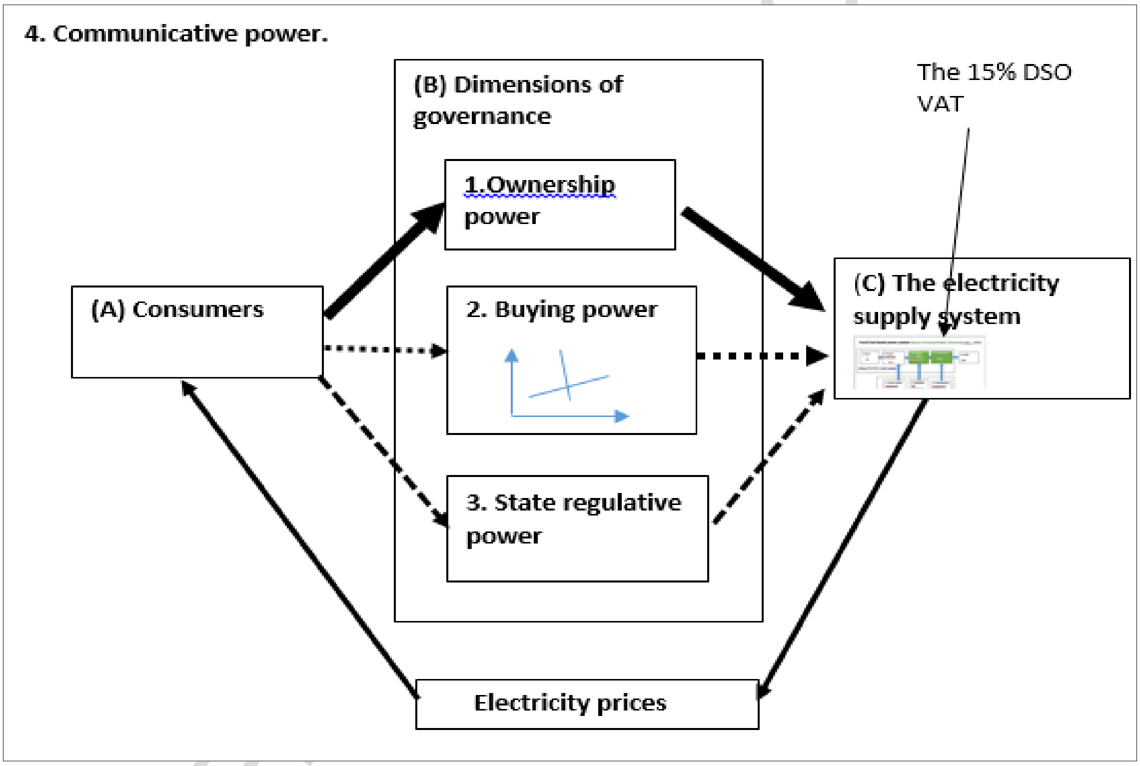

Figure 3. The four dimensions of power in the DSO part (15% of value-added) of an electricity supply system.

Reference: [24]

(1) Consumer ownership power can be executed rather efficiently via the elected consumer representatives, by an open and competent statistics comparing the performance with the performance of other DSOs. This dimension is often forgotten about in theories on regulation of natural monopolies [22].

(2) Consumer buying power is very limited, as the DSOs, are natural monopolies. The only consumer buying power is to buy less or avoid buying more.

(3) The state regulative power can be executed by means of cost control, bench marking, price ceiling, etc.
(4) The communication power in the shape of openness of information is a prerequisite for both the execution of consumer ownership power and state regulative power. This dimension is not efficiently dealt with in the literature on regulation of natural monopolies.[22]

In figure 3, the thick arrows illustrate how strongly the consumer ownership power has been executed in the Danish electricity system. The weakness of consumer buying power is illustrated by the dotted line. Consumer power through state regulation has generally been a framework regulation, where the state by legislation amongst others required a nonprofit regime, where the profit should remain in the electricity company and could not be used outside the electricity area for other purposes. It is important to emphasize that consumer municipality ownership cannot be seen as isolated. As illustrated in figure 3, we deal with a governance system consisting of consumer ownership of (a) a natural monopoly, (b) embedded in a public nonprofit regulation regime and in (c) a democratic system with a relatively high level of transparency and openness of information.

Low price incentives in the Danish nonprofit/consumer profit governance system

The Danish nonprofit public regulation regime remained until 2004[1], where it was replaced by an income frame regime as discussed later, and the DSO prices from after 2004 refer to a public regulation income frame[2] regime. The Danish regulation regime has historically *been price efficient due to a nonprofit public regulation* ***in combination with*** *an efficient consumer ownership regime*.. Any efficiency gain was paid back to the consumers via a price reduction. So the system is dynamic, as it has a "consumer profit through lower prices" incentive, which in consumer and municipality owned DSOs is supplemented by full openness regarding prices and costs. In the yearly published electricity price statistics, see[25], any consumer can read whether his/her electricity company is cheaper or more expensive than any other Distribution System Operator (DSO). If one DSO has much higher prices than the neighbor DSOs, this is discussed at the annual meetings of the consumer representatives, and the DSO director will be kept responsible for cases with too high prices. This means that despite the impossibility of having price competition in a natural monopoly DSO, consumer ownership *replaces an impossible price competition with possible production factor competition*. This system of consumer representatives and openness of information thus represents a dynamic incentive system that seems to result in lower consumer prices.

International statistical evidence for lower Danish electricity prices

The dynamics of the above governance regime represents in itself an incentive for lower consumer prices. But is this incentive system also resulting in lower Danish electricity prices?

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[1] By nonprofit regulation is meant that a DSO is not allowed to remove any profit from the company for other purposes outside the energy company

[2] By income frame regulation is meant that a DSO has the right to charge the consumers up to an income frame defined by the public regulator.

Since the 1980s, Denmark has had electricity prices which are much lower than the prices in many other EU countries. In the period 1978-1996, before the liberalization of the electricity system, the electricity prices including taxes for Danish industry were on average 10-15 percent lower than in the UK, the Netherlands and Germany[26][27]. In 1995, Danish electricity prices were around 50% below the EU 15 average electricity prices for industry. In 2000, Danish electricity prices for industry were 18 percent lower than the EU average [28].

After Denmark started participating in the Scandinavian Nordpool electricity market in 2000, this low electricity price position has been maintained, at it is illustrated in figure 4.

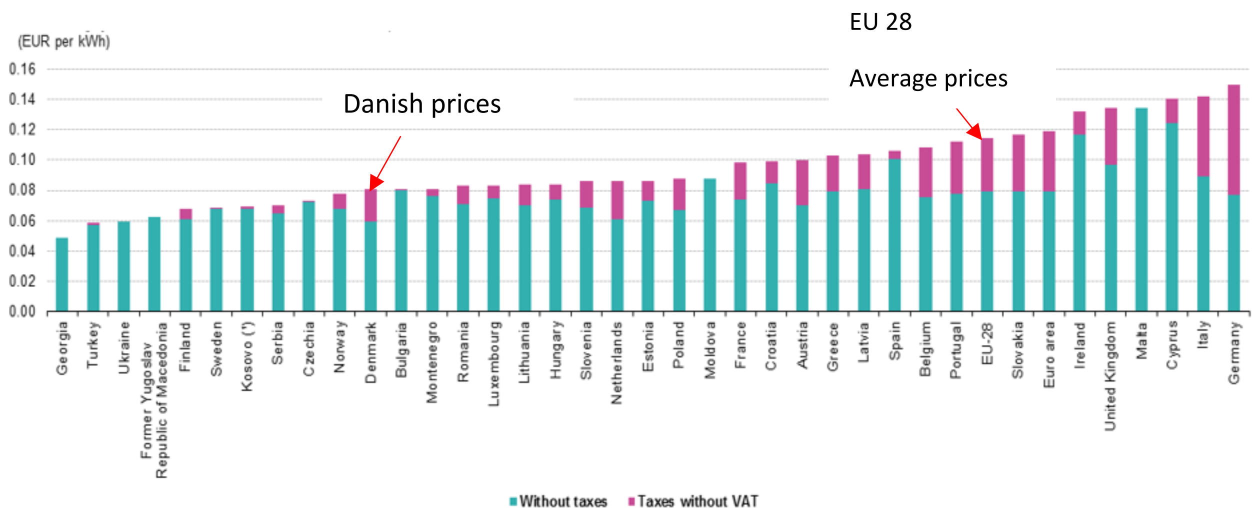

Figure 4. 2017 electricity prices for non-household consumers first half 2018.
Reference: [29]

In figure 4, the Danish electricity price for industry is between the lowest in EU 28, despite the fact that the electricity price includes Public Service Obligation (PSO) payments (the purple part of the column for Denmark) [30] used for subsidies paid to the development and implementation of renewable energy technologies in the Danish energy supply system.

National statistical evidence for low price incentives in a consumer owned DSO

The above international comparison gives evidence that the Danish consumer owned system is price efficient and generates comparatively low electricity prices. Amongst the Danish DSOs, we have one shareholder owned company named RADIUS, a large DSO serving the Copenhagen area.

Table 1 compares the distribution costs in these two Danish DSOs, KONSTANT (Aarhus area and consumer owned) and RADIUS (Copenhagen area and owned by external shareholders).

Consumers annual consumption in kWh	2000 Eurocent/kWh	4000 Eurocent/kWh	15.000 Eurocent/kWh	100.000 Eurocent/kWh	250.000 Eurocent/kWh
1. RADIUS (R)	6	5	4.25	4.16	1.74
2. KONSTANT (K)	3.88	4.29	2.64	1.72	0.93
3. (R) more expensive than (K) Eurocent/kWh	2.12	0.57	1.61	2.44	0.81
4. So much is RADIUS more expensive than KONSTANT.	55%	83%	116%	142%	86%

Table 1. Comparison of electricity distribution prices in RADIUS (External shareholder ownership) with KONSTANT (consumer ownership).
Reference: [25]

The result of the comparison is stunning with distribution prices in the shareholder company RADIUS that are 55 to 142 percent higher than in the consumer owned DSO company.

Box 1: Does consumer and municipality ownership give low prices that may facilitate financing of the transition to renewable energy systems?

a. A citizen (consumer/municipality) ownership system combined with a nonprofit public regulation gives a ”consumer profit” incentive for low prices.
b. Statistics show that Danish electricity prices for industry have been amongst the lowest in Europe.
c. A price comparison within Denmark between the DSOs RADIUS and KONSTANT strongly indicates that consumer ownership results in relatively low prices.

a, b and c have given economic space to a first mover “premature” and expensive introduction of renewable energy technologies without putting Danish industrial competitiveness at risk.

Regarding natural monopolies, it can be concluded that consumer/municipality ownership in a ”nonprofit regime” gives low prices that may give economic space for the extra costs of being a first mover within a renewable energy development and implementation.

4.2. Are the consumer and municipality owned Distribution System Operators (DSOs) able to participate in an innovative transition to renewable energy?

Until 2004, the DSOs were subdued to a double regulation with consumer ownership embedded in a public nonprofit regulation regime as shown in figure 3 above.

In 2004, the nonprofit public regulation regime was replaced with an income frame regulation, where the public energy inspectorate each year announces an income frame for the specific DSO.

The regulation after 2004 consists of:

a. A *top down* cost and income frame regulation designed and controlled by the national authorities,

b. A *bottom up* cost and price regulation by means of the consumer or municipality/state ownership governance.

The income frame regulation consists of 1-3 below.

1. A price cap based on 2004 costs per kWh
2. This cap is regulated upwards with the inflation index every year, and also frequently regulated downwards in order to further increase productivity.
3. Economic benchmarking

The points 1-3 together constitute an *income frame* by which the DSO is allowed to charge its consumers. Compared to the former nonprofit regulation, this means that the DSO can earn a profit, if their costs are below the income frame. This change gives incentives for innovative activities developed and implemented by the DSO.

Regarding price regulation in the consumer and municipality owned distribution companies, there is still an incentive to use profits for lowering the consumer prices. But now the consumer representative can decide to use parts of the profit for common good projects.

The downward pressure on prices from consumer owned DSOs seems to be stronger than the above points 1-3 concerning the state induced income frame regulation.

Consequently, the costs in the consumer owned DSOs are mostly lower than the electricity price allowed for by the income frame regulation points 1-3 above. As a result, the difference between costs and income frame regulation in general gives the DSOs profits that can be used for both "the common good" projects, such as for instance green projects in their area, and reduction in consumer prices. In the case of the Aarhus area DSO, KONSTANT, the consumer representatives have decided to use 50 percent of the profit as a price refund paid back to the consumers, and 50 percent for "common good projects" such as renewable energy projects, primary school education projects, green cities, social responsibility projects in their companies, etc. In a shareholder company like RADIUS, 100 percent of the profit is used as dividend to the shareholders. The present portfolio of KONSTANT is 100 MW solar and wind power, and KONSTANT has plans for further 50 MW wind power before the end of 2020.

Box 2: Are the consumer and municipality owned DSOs able to participate in an innovative transition to renewable energy?

- A consumer owned DSO like KONSTANT tends to use the profit in an income frame regulation regime for green projects and lower electricity prices, whereas a shareholder owned DSO like RADIUS uses the profit for dividends. This is one of the reasons why the DSO KONSTANT has lower distribution prices than the DSO RADIUS, see table 1.

- In the present governance system, the combination of top down income frame regulation and consumer profit cost control also leaves profit for a broad range of "green projects". To which degree a profit should be used for such projects or paid back to the consumers as lower prices is decided upon by the elected consumer representatives.

- Nevertheless, in our analysis of DSO projects, we have not yet seen investments in integrative smart energy systems that are able to solve the challenge of integrating large shares of fluctuating renewable energy sources. In the future, this is naturally a possibility.

5. Preliminary analysis of transaction costs and consumer ownership in a transition to 100% renewable smart energy systems

There are two scenarios built into the present discourse regarding the future integration of large shares of fluctuating renewable energy sources.

A centralization scenario, where the large power companies own all the power producing units (mainly wind power and photovoltaic) and where this is supplemented with an increased interconnector capacity. The main idea is to export wind power, when there is a wind power surplus, and import some power capacity, when there is insufficient wind power.

A *decentralization* scenario, also often called the smart energy system road [31][32], where the different energy sectors, heat, electricity, transportation and biomass are integrated in such a way that for instance excess wind power is supplying heat pumps and heat storages in district heating systems. Eventually, this will lead to a development where wind power is used to produce fuels

[33]. Several studies indicate that this leads to future technical and economically sustainable solutions[34].

These two scenarios involve different kinds of transactions and different kinds of organizations. In order to analyze the general relationship between ownership structure and transaction costs in a renewable energy system, it will first be outlined how the technical change results in a change in the economic cost structure of the supply system. Second, a preliminary analysis of how this change is likely to affect transaction costs is described.

5.1 The value added gets closer to the consumer in a 100% renewable energy based electricity supply system

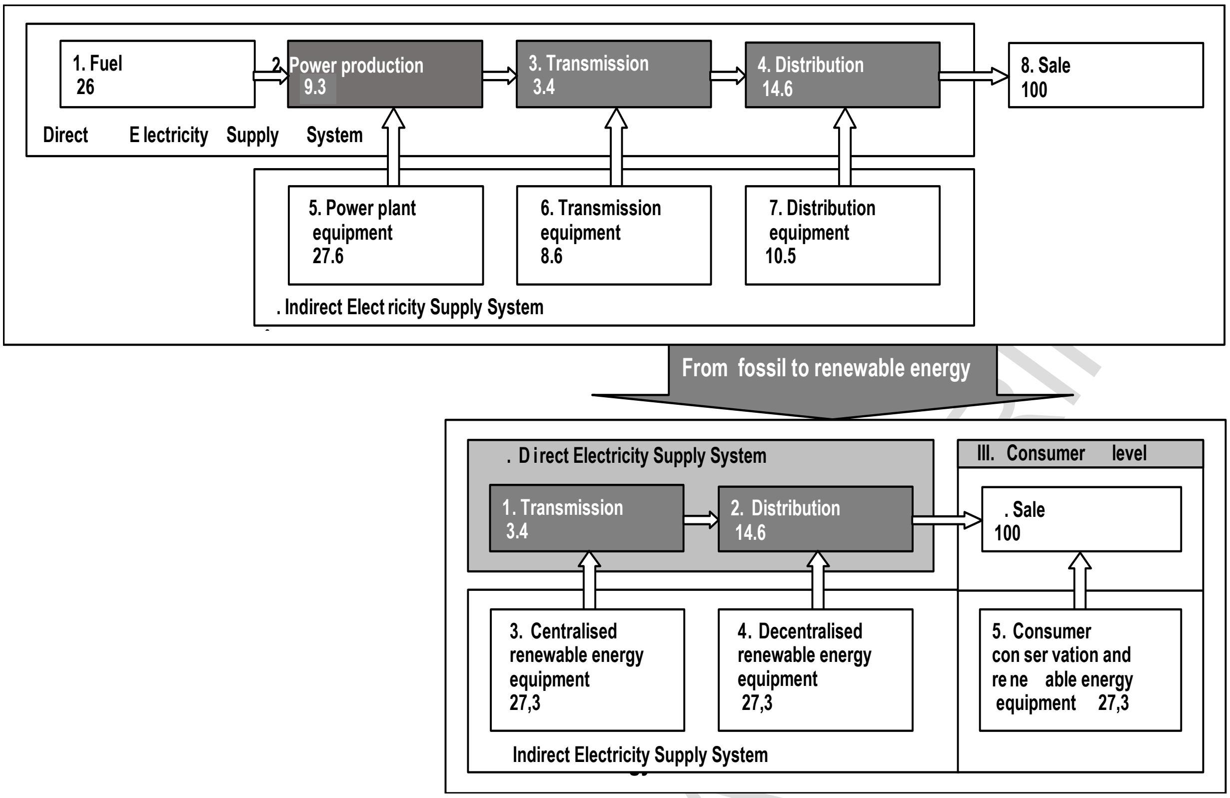

Figure 6. The change in value-added profile connected to a transition from a fossil fuel based to a renewable energy based system.

Reference: [23].

In the traditional fossil fuel based system as shown in the upper part of figure 6, a 100 DKK sale at the consumer level will divide the value added between the different levels of vertical integration, as shown in the upper part of the figure.

The bottom part of figure 6 demonstrates an example of value-added distribution in an energy conservation and renewable energy system. The assumption in the principle sketch in figure 6 is that the renewable energy system can produce energy at the same price, time and quality while using the same transmission and distribution grids as the fossil fuel system.

Figure 6 illustrates that the value-added chain of renewable energy and energy conservation technologies clearly differs from the value-added chain in a fossil fuel based electricity supply system within the following areas:

a. In the renewable energy based value-added chain, the fossil fuel value-added part has disappeared and *has been replaced by investment in renewable energy capital equipment which is produced by organizations in the indirect electricity supply system, outside the direct electricity supply system.*

b. In this system of factory produced electricity "automatons", the maintenance functions, at least at the decentralized and consumer levels, will mainly be performed by the manufacturers of wind turbines, solar cells, wave energy plants, hydrogen production systems, the electricity battery charging system, etc. The value added in a specific power production organization will be reduced considerably or disappear entirely as the day-to-day work on the power plant has been replaced by automatons often requiring maintenance from the manufacturers outside the electricity supply system.

c. As a consequence, *distant employees at the coal mining and coal power plant level are replaced by nearby employees at the renewable energy equipment factory and the factories making components to and maintaining and installing the integration infrastructure.* And also for the production of parts for the running operation and maintenance of these systems.
d. The value added in the Direct Electricity Supply system (including fuels) has consequently been reduced from 53.3% of the consumer price to the 18% value added in the electricity distribution and transmission system or by 66%.
e. In this case, the consumption at the onsite level has been reduced by 27.3% and altogether the value added to be supplied from the direct electricity supply system has been reduced by around 75%.

A short way of expressing this change is that in a 100% renewable energy system, electricity is produced by automatons that are produced at factories in the indirect electricity supply system and not by power companies in the direct electricity supply system. Power companies are organizing large on- and offshore wind turbine plants, but this activity does not include the value added by producing and maintaining wind turbines, and therefore only comprises a minor part of the value added linked to power production; especially when compared with the role of power companies in a fossil fuel based power system.

As we can see in points a, b and c above, this development not only changes value-added distribution, *but also shifts the character and location of the investment and operation and maintenance of the integration infrastructure*. This is a change towards being physically and organizationally closer to the consumer and simultaneously requiring more local and regional coordination. This change will be discussed later in this paper and related to the needed future ownership structures.

The large energy company organizations inherited from the fossil era have been specialized in coordinating a global allocation and distribution of fossil fuels. The transition to renewable energy implies a physical and economic decentralization which reduces the need for global and international coordination. Hence, the character of transactions is different in the renewable smart energy system than it has been in the fossil era.
The decentralization makes the coordination task more local in geographical terms – more close to the consumer and more distant to the old organizations of large energy companies.
The organizational – and often geographical – distance arising between large energy companies and the transactions in a smart energy system questions the efficiency of the large organizations of old energy companies and may provide the grounds for a competitive advantage to consumer close organizational forms. The costs of transactions that allocate energy across sectors but are geographically local may be reduced by local organizations.

The transition also encompasses a dramatic reduction in the value added to the direct electricity supply system, as this (direct) system is changed to factories not owned by the power companies, producing energy automatons in the indirect electricity supply system. In addition, the transmission system in Denmark is owned by a state owned organization, Energinet.dk, and the DSOs are mainly owned by consumers and municipalities. Thus, the present large power production companies will, after the transition*, have a much reduced value-added share* linked to the implementation and operation of large renewable electricity plants.

What can we learn from the discussion of the above described shift in both value added percentages in general, value added shift from the direct to the indirect energy supply system, and a shift in the location of the value added from distant fossil fuels to nearby integration infrastructures?

The centralization scenario defined in the beginning of this section can be seen as a strategy suited for large energy companies to maintain their prominent role in the supply system.

The *decentralization scenario* is pleading for a local inter sector integration of the fluctuating renewable energy sources. See for instance [35] where the authors demonstrate how 4th generation district heating can play a role in smart energy systems integrating fluctuating renewables and [36] outlining how the different parts of the district heating system can be optimized within a smart energy systems context. However, how can the transition to renewable energy systems and conservation be governed?

6. Regulation and the transition from stored fossil fuels to fluctuating renewable energy systems

The transition from fossil fuel systems to smart renewable energy systems encompasses that a large share of the value added is *moved from distant coal mining and power plant activities to the consumer near renewable energy integration infrastructure and wind turbines.*

6.1. Smart energy systems and the need for consumer/municipality ownership

The transition process from coal extraction and large coal fired power plants to renewable energy and conservation requires new types of integration infrastructures such as *smart energy systems* that needs a multifaceted governance system to support the coordinated investments and operation and management of integration technologies. This encompasses investments in district heating, heat storage systems [36], transportation systems [37], heat pumps, solar heating etc., and that all these technologies are dimensioned to be able to handle large shares of fluctuating renewable energy technologies. Concurrently there is a need for systematic policies that make the integration of fluctuating renewable energy happen [36]. Furthermore this should be combined with "in time" investments in energy conservation.

Some of the different technological components are shown in table 2. They are both much closer to the consumers than coal mines and large coal fired power plants and mainly owned by the consumers, as also shown in table 2. Furthermore, smart energy systems require a multitude of coordination activities both with regard to investments in integration technologies and the operation and maintenance of these.

Technologies that should be integrated	Present ownership
1.House insulation	Consumer

2.District heating systems	Consumer coops/municipalities
3. Heat pumps	Consumer coops/municipalities
4.Industrial heat	Local firms
5.Biomass use	Local producers
6.Wind power	Consumers or large companies
7.Electric cars	Consumers
8.Electricity distribution systems	Consumer coops/municipalities
9.Solar power	Consumers and/or consumer coops

Table 2. The present owners of the components that should be integrated in a smart energy system

When integrating electricity and heat, consumer distant supply systems are replaced by consumer nearby activities. Consumer distant fossil fuels are replaced by the consumer near integrative facilities of smart energy systems.

In addition to transaction cost theory in the Coasean tradition [38][39], policies for supporting a multitude of coordination activities may also be inspired by the arguments against central planning in the Austrian tradition [40][41]. As the complexity of coordination increases, the costs of conveying the adequate level of information to a distant owner may increase considerably. This is illustrated with the needed coordination activities listed below.

- Such distant companies would need to buy the local consumer and municipality owned district heating systems. This would be very difficult, as these companies are subdued to a nonprofit or consumer profit regime.
- They also would have to invest in the right size of 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.
- A multitude of co-ordination activities should be developed, dimensioning investments in the different technologies so that they supplement each other and concurrently establish the right amount of energy conservation “in time” with a conservation level that supports the right low temperature district heating systems. It seems probable that it will be much easier for the owners of houses, district heating systems, etc. to implement and operate and manage these technologies, than for distant foreign companies.
- It is difficult for distant owners to establish onshore wind power in Denmark, as local citizens want influence and benefits from energy plants to counterbalance the inconvenience from such plants. Therefore a large local ownership share is mostly requested.
- Building onshore and nearshore wind power may result in political conflicts, as distant potential owners like the Swedish power company Vattenfall do not pay local taxes and do not supply any profits to local actors. Local inhabitants in distant owner models will get the noise and visual disadvantages, but no benefits from the projects. An ongoing case is the conflict between the Swedish state owned power company Vattenfall and the local community [42].
- Settling agreements between distant large energy companies and local citizens are arrangements that themselves are surrounded by large transaction costs. These costs are

typically distributed between the local citizens, the distant energy companies and public authorities. When energy companies avoid settling agreements and their associated costs with local citizens, the result tends to be a social conflict and/or resistance towards the consumer close renewable energy installations.

Due to the complicated regulations and communication tasks, it seems difficult for large distant power companies both to design and dimension the right investments and to operate these in an efficient way complying with local wishes, capabilities and technological conditions. Furthermore, as illustrated in table 2, these distant companies do not have the initial ownership governance power of the smart energy system technologies nor the decentral multitude of information needed to handle and behave strategically and tactically efficient. Consequently, they are comparatively handicapped as actors in the development of a decentralized smart energy system based on renewable energy.

7. Conclusion and policy discussion

Since around 1980, Denmark has been a first mover within the development and introduction of new renewable energy and energy conservation technologies. Being a first mover means that new technologies are subsidized and introduced at the market before they have reached technical and economic maturity. It simply costs a lot of money to start and to continue this technological learning process.

Meanwhile, the Danish energy system encompassing both the electricity system and the district heating system has been, and to a large extent still is owned by consumers and municipalities. Concurrently, the Danish electricity prices have been distinctly lower than electricity prices in most European countries. And the consumer owned DSOs are far cheaper than the one shareholder owned Danish DSO.

The reason behind these low electricity prices mainly seems to be a double price control system consisting of a combination of a nonprofit and, since 2004, an income frame with public price regulation as well as a consumer profit system regulation, which is not dealt with in most natural monopoly regulation theory [22], where efficiency improvements are paid back to the consumers in the shape of reduced prices.

We can conclude that the price for being a first mover has received a major contribution from the low Danish electricity prices. The profit from the consumer ownership and nonprofit governance model seems to have given compensation for the first mover costs to such an extent that Danish industry has had lower prices than average EU prices, even after having paid for the expensive first mover learning process.

A preliminary analysis has been conducted regarding the transaction cost attributes of consumer and municipality ownership organizations with regard to their coordination of the multitude of hour-by-hour operations and investments in the different components of integrated smart energy systems.

From this analysis, we can draw the following conclusions:

Firstly, the transition to a smart energy system brings the value added much closer to the consumers than in a fossil fuel system.

Secondly, in a smart energy system, a larger part of the energy system will be energy automatons produced in the indirect energy system or factories where energy equipment is built.

Thirdly, in a smart energy system, the technologies that have to be integrated and coordinated are mainly owned by the consumers or municipalities.

Fourthly, the transaction to smart energy systems encompasses a multitude of coordination tasks that are very close to the consumer. Therefore consumer ownership would have a comparative advantage as managers of these tasks.

Due to these four reasons, it is a reasonable to conclude that consumer and municipality ownership in the right governance system can result in lower coordination transaction cost than the coordination by large energy companies.

The conclusion is called preliminary, as there surely is a need for further analyses of the interrelationship between ownership and transaction costs in smart energy systems.

Regarding policies, there are several institutional hindrances that should be removed to support consumer ownership linked to the implementation of the smart energy system. In Denmark, taxes on wind power for heat are high and there is no tax on biomass. This enhances the introduction of wind power, heat pumps and heat production for district heating. And there are subsidies to centralized solutions with interconnectors, but no EU subsidies for the integration of fluctuating energy in smart energy systems. The TSOs are governed by a legislation that is not designed to support integrative smart energy systems, but rather to support investments in interconnector solutions. The aim of this paper has not been to give detailed policy suggestions. But a major policy principle in Denmark and in the EU could be that the potentials for local and regional integration solutions should always be evaluated before any potential investments are made in a centralized model with transnational transmission lines. Moreover, consumer and municipality ownership should be furthered as the ownership model for natural monopolies. This might be supported by the Renewable directive REDII, article 22 on "Renewable energy communities" which could constitute a framework for consumer empowerment through renewable energy communities. More analysis of this possibility should be performed in future investigations.

References

[1] Handelsministeriet. Dansk Energipolitik 1976. Copenhagen 1976: 1976.

[2] Blegaa,S et al 1976. Skitse til alternativ energiplan for Danmark. OOA and OVE; 1976.

[3] Energiministeriet. Energiplan 81. Copenhagen 1981: Energiministeriet; 1981.

[4] Hvelplund, F, Illum, K, Jensen, J, Meyer Niels, Sørensen B. Energi for fremtiden. Borgen; 1983.

[5] Hvelplund, F, Meyer, N, Morthorst, P, Munksgaard, J, Karnøe, P, Hasberg K. Policies for a transition to 100% Renewable Energy Systems in Denmark before 2050. http://www.ceesa.plan.aau.dk/digitalAssets/114/114489_54766_wp4-final-2012.pdf; 2012.

[6] Mathiesen BV, Lund H, Hansen K, Ridjan I, Djørup S, Nielsen S, et al. IDA's Energy Vision 2050. A Smart Energy System strategy for 100% renewable Denmark. Aalborg: 2015.

[7] Klimarådet. No Title 2017:6.

[8] Hvelplund F, Djørup S. Multilevel policies for radical transition: Governance for a 100% renewable energy system. Environ Plan C Polit Sp 2017;35. doi:10.1177/2399654417710024.

[9] Lund H, Mathiesen BV, Connolly D, Østergaard PA. Renewable Energy Systems - A Smart Energy Systems Approach to the Choice and Modelling of 100 % Renewable Solutions. Chem Eng Trans 2014;39:1–6. doi:10.3303/CET1439001.

[10] Hvelplund F, Østergaard PA, Meyer NI. Incentives and barriers for wind power expansion and system integration in Denmark. Energy Policy 2017;107:573–84. doi:10.1016/j.enpol.2017.05.009.

[11] Hvelplund F, Möller B, Sperling K. Local ownership, smart energy systems and better wind power economy. Energy Strateg Rev 2013;1:164–70. doi:10.1016/j.esr.2013.02.001.

[12] Hvelplund F, Meyer N, Morthorst P, Munksgaard J, Karnøe P, Hasberg K. Policies for a transition to 100% Renewable Energy systems in Denmark before 2050. 2012.

[13] Kerr S, Johnson K, Weir S. Understanding community benefit payments from renewable energy development. Energy Policy 2017;105:202–11. doi:10.1016/j.enpol.2017.02.034.

[14] Bauwens T, Gotchev B, Holstenkamp L. What drives the development of community energy in Europe? The case of wind power cooperatives. Energy Res Soc Sci 2016;13:136–47. doi:10.1016/j.erss.2015.12.016.

[15] Sperling K, Hvelplund F, Mathiesen BV. Centralisation and decentralisation in strategic municipal energy planning in Denmark. Energy Policy 2011;39:1338–51. doi:10.1016/j.enpol.2010.12.006.

[16] Wirth S. Communities matter: Institutional preconditions for community renewable energy. Energy Policy 2014;70:236–46. doi:10.1016/j.enpol.2014.03.021.

[17] Jensen LK, Sperling K. Who should own the nearshore wind turbines? : A case study of the Wind & Welfare project. Aalborg: Department of development and planning, Aalborg University; 2016.

[18] Kooij H-J, Oteman M, Veenman S, Sperling K, Magnusson D, Palm J, et al. Between grassroots and treetops: Community power and institutional dependence in the renewable energy sector in Denmark, Sweden and the Netherlands. Energy Res Soc Sci 2018;37. doi:10.1016/j.erss.2017.09.019.

[19] Porter, Philip, K; Scully W. Economic efficiency in cooperatives. J Law Econ 1987;30:489–512.

[20] Enke S. Consumer Coopertives and Economic Efficiency. Am Econ Rev 1945;35:148–55.

[21] Hill R. The case of the Missing Organization:Cooperatives and the Textbooks. J Econ Educ 2000;3:281–95.

[22] Joskow PL. Chapter 16 Regulation of Natural Monopoly. Handb. Law Econ., vol. 2, 2007, p.

1227–348. doi:10.1016/S1574-0730(07)02016-6.

[23] Hvelplund F. Electricity reforms,Democracy and Technological Change. Department of Development and Planning,Aalborg University; 2001.

[24] Hvelplund F. Fra fælleseje til fjernejerskab og monopolkontrol. In: Christensen EC& P, editor. Fælleder i Forand. 1st ed., Aalborg: Aalborg Universitetsforlag; 2007, p. 282.

[25] Energi D. Elforsyningens nettariffer og priser per jan. 2018. Dansk Energi; 2018.

[26] Forening DE. Elforsyningens ti-års statistik. Danske Elværkers forening; 1988.

[27] Forening D elværkers. Elforsyningens ti-års statistik 1988-1997. Danske Elværkers Forening; 1999.

[28] Eurostat. Gas and Electricity Statistics 1990-2005. EU commission; 2006.

[29] Eurostat. Electricity Prices for non-household consumers,first half 2018 2018:1.

[30] Energistyrelsen. Aktuel PSO tarif 2019:3.

[31] Connolly D, Lund H, Mathiesen BV. Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union. Renew Sustain Energy Rev 2016;60:1634–53. doi:10.1016/j.rser.2016.02.025.

[32] Lund H. Renewable Energy Systems: A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions: Second Edition. Elsevier Inc.; 2014.

[33] Ridjan I, Mathiesen B, Connolly D, Duic N. Terminology used for renewable liquid and gaseous fuels based on the conversion of electricity: A review 2016;112:3709–20. doi:10.1016/j.jclepro.2015.05.117.

[34] Lund H, Hvelplund F, Østergaard P, Möller B, Mathiesen BV, Connolly D, et al. Renewable Energy Systems. Elsevier; 2014. doi:10.1016/B978-0-12-410423-5.00006-7.

[35] Mathiesen BV, Lund H, Connolly D, Wenzel H, Østergaard PA, Möller B, et al. Smart Energy Systems for coherent 100% renewable energy and transport solutions. Appl Energy 2015;145:139–54. doi:10.1016/j.apenergy.2015.01.075.

[36] Hvelplund,F; Sperling K. From stored fossil fuels to fluctuating renewable energy-The Danish case, Clayes & Castells Publishing; 2018, p. 33.

[37] Ridjan I, Mathiesen BV, Connolly D, Duić N. The feasibility of synthetic fuels in renewable energy systems. Energy 2013;57:76–84. doi:10.1016/j.energy.2013.01.046.

[38] Coase R. The Nature of The Firm. Economica 1937;4:386–405.

[39] Coase RH. The Firm, the Market, and the Law. University of Chicago Press; 1988.

[40] Hayek FA. Economics and Knowledge 1937.

[41] Hayek FA. The Use of Knowledge in Society. Am Econ Rev 1945.

[42] Olsen, Emil;Chriistiansen H. Forslag til til vindmølleprojekt Nørrekjær Enge II 2016:2.

Highlights

Consumer ownership of natural monopolies plus non profit governance gives low prices

Low prices pays for the extra costs of early introduction of green energy technologies.

Consumer ownership gives low renewable energy integration transaction costs.

100% renewable energy mainly consists of consumer near energy systems.

Smart energy system technologies are at the outset mainly consumer owned.