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Institutional Innovation for Technological Transition: A Taxation Principle for Renewable Energy Systems

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INSTITUTIONAL INNOVATION FOR TECHNOLOGICAL TRANSITION: A TAXATION PRINCIPLE FOR RENEWABLE ENERGY SYSTEMS[1]

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Abstract

The technological transition towards a renewable energy supply requires institutional innovation in the energy system. Based on recent insights from technical system analysis, this paper proposes a new electricity tax model. The concept is developed on basis of a case study of the Danish district heating sector. However, it addresses a wider and more permanent allocative issue for a renewable energy system; the competition between biomass and wind energy. The concept is designed to achieve parity between biomass and wind energy without boosting the demand for fossil fuel based electricity. The effect of the tax concept is analysed. The proposal secures desirable private economic incentives while improving the tax revenue for the state, compared to the current empirical trend.

Keywords; Energy policy; Energy taxation; Wind energy; District heating; Renewable energy systems; Smart Energy Systems

Introduction

Several countries have initiated a technological change from stored fossil fuels to fluctuating renewable energy supply, primarily in the form of wind power and photovoltaics. The change in the technical properties of the production basis also requires organisation and institutional changes. From an economic organisational point of view, the inherent storability provided by the fossil fuel reserves is lost in the transition to an energy supply based on wind turbines and photovoltaics. The fluctuating and fleeting nature of the renewable resources necessitates the creation of new storing services in order to coordinate the delivery of energy services with the end use needs. For stimulating and sustaining the creation of adequate storage facilities, new institutional structures are needed [2][3].

These institutional structures, however, cannot be meaningfully discussed and developed without specifying the physical and technical basis of future energy systems. In our view, the discussion of market design, tax structure etc. must be based on technical energy system scenarios which are

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[1] This working paper is a stand-alone version of content also made publicly available in Ch. 8 of the PhD thesis *Fjernvarme i forandring: Omstillingen til vedvarende energi økonomisk perspektiv (2016)* by the same author [1]. The working paper was written during the period 2015-2016.

documented to be both technically feasible and in line with energy policy goals. In this paper we will propose and evaluate a taxation concept designed to meet some of the important coordination challenges that arises in a renewable energy system.

Before heading to the concrete proposal, it is necessary to elaborate on the technical opportunities which form the basis of our proposal and subsequently describe the methodological aspirations of our work.

Technical synergies and potentials in the transition

A paradigm of research within technical system analyses has demonstrated large synergies in dealing with the fluctuating supply through an energy systems approach. By 'energy system approach' it is meant that the challenges of a fluctuating supply in the electricity sector, is not only approached as an electricity sector challenge. Instead, an energy system approach includes the total energy supply as meeting the electricity demand, heat demand and transport demand. Such a broader approach to system designs reveals that all energy services can be more effectively met by integrating the electricity, heat and transport sector . This implies that, in a renewable energy system, not only traditional electricity demand but also heat and transport services could be supplied by wind turbines in hours of high wind. Thus, an energy policy promoting such cross sector integration could more effectively reduce fuel consumption in the energy system as a whole [4].

In traditional systems supplied by thermal electricity generation, a range of countries have utilised the associated waste heat to meet heat demand by distributing it as hot water through urban heat networks, also known as district heating [5]. This build-up of combined heat and power generation has contributed to reduce the fuel consumption in the heat sector by replacing the need for individual heat boilers. Thereby, an integration of the heat and electricity sector has provided improved fuel efficiency for the energy system as a whole.

As the capacity of wind turbines and photovoltaics is increasing, new potentials arises for an even closer integration of the sectors. In high wind, the associated peak production in the electricity sector is likely to exceed the traditional electricity demand. If production exceeds demand, in the present energy system configuration, wind curtailment is needed in order to insure the stability of the grid (or more specifically to keep the frequency at the same level). Such actions represent an economic efficiency loss since the short term marginal cost of wind power production is zero. Instead of shutting down wind turbines, an integrated energy system would be able to exploit the excess wind power to reduce fuel consumption in meeting heat, cold and transport demands. For thermal services, heat pumps or electric chillers could convert electricity to heat and cold with high efficiencies and thereby bring about large reductions in fuel consumption [6][7]. If those services are supplied through thermal grids, the use of central thermal storages would make it possible to respond flexibly to the fluctuating electricity supply in a cost effective way [8]. Such technical arrangements may provide vital storage facilities for a renewable energy system to be realised. Further, electrified transportation as well as so-called electrofuels has the potential to reduce primary fuel consumption in the transport sector through utilisation of wind energy [9][10]. Likewise, the synthetic fuels and gases can be stored cost effectively [8].

Such scenarios for a future energy system are well documented and demonstrated by simulations in the technical literature. The phrase Smart Energy Systems has in recent years been established for describing an energy system which is assessed and designed from a cross-sectoral perspective in order to handle the fluctuating primary supply that characterises a renewable energy system. Specifically, the institutional concept developed in this paper is based on analyses made in the energy systems simulation tool EnergyPLAN. EnergyPLAN is developed at Aalborg University and is widely applied for designing and simulating energy systems, especially in instances of high renewable energy shares [11]. EnergyPLAN is capable of simulating a given energy system scenario at an hourly basis through a whole year [12]. Simulating at an hourly basis is important for detailed analysis of renewable energy systems with large amount of fluctuating primary supply [4]. Further, the inclusion of the total energy system in the model makes it possible to discover cross-sectoral synergies.

One of the countries at the forefront of the technological transition, as measured by the share of renewable sources in the electricity supply, is Denmark. In Denmark, wind turbines generated around 40 percent of overall electricity supply in 2014 and 2015 [13][14], and current political goals aim for a 50 percent wind energy share in electricity supply by 2020. When countries reach such high shares of renewable energy, questions about how to deal with the fluctuating nature of the energy source become pertinent [4]. The Danish energy sector is therefore an interesting case of the organisational challenges that are derived from the technical change.

As the following economic analysis will address the present Danish institutional structure, the technical reference is based on scenarios for a fossil free energy supply in Denmark, primarily the CEESA research project [15] and IDA's Energy Vision 2050 [8].

We will focus at the current conditions for achieving the synergies described above between the Danish electricity and heating sectors.

From connoisseur to creator

"Read Plutarch and Lucian, men of the most generous capacities and the widest culture: the Fenélin and Voltaire of a mature age. These admirable writers have, alas! One great defect: they know too much for their own good. The connoisseur has replaced the creator. Such a community faces too many incompatible choices; and as a result, fashion takes the place of organic necessity, and novelty becomes a substitute for rational development " [16]

In line with the needs described in the above Mumford quote, we intend to make it possible to provide usable policy recommendations as an output of our studies. In the same way as it is required from engineers to design technical solutions at a concrete level. In order to formulate usable policy recommendations, it is essential to make interdisciplinary studies of the interrelations between concrete technical scenarios and concrete institutional designs.

Before presenting the regulatory concept and analysing its consequences, we will give a few remarks on the methodological and scientific perspectives and motivations of the work.

It is a difficult societal task to design and develop an institutional structure capable of sustaining technological change. It does essentially require institutional innovation since the technological system it is supposed to regulate—that is, a 100% renewable energy system--has no predecessor. Solving this task requires deep insight into the objects of regulation. Therefore, we regard it as important that scholars attempt to formulate institutional concepts which may inspire the empirical process of institutional change. This scientific ambition requires an interdisciplinary methodological concreteness which is not so widely seen in international academic publications within social sciences--and maybe in particular--economics. But it is important that scholars independent of political and economic interests enter this institutional innovation process since the success of such innovation is a premise for the technological change to succeed. The institutional structure of a renewable energy system is unknown land and therefore a scientific subject. Due to the character of science, this unknown land must be studied objectively and transparently. Due to the nature of the material, it has to be studied at a concrete level.

There are some general allocative challenges in the transition to a renewable energy system. These general challenges have been described in the sections above. While the challenges are general, it is our belief that those challenges are materialised in very specific forms. Accordingly, they must be assessed at a concrete level in context of the specific institutions and technologies. This approach, which elsewhere has been termed Concrete Institutional Economics [17], is related to mainstream paradigms of New Institutional Economics. Institutional economics stresses that economic systems must be assessed in their institutional context and the literature in general contributes with many very interesting and insightful writings [18][19]. However, often the various branches of institutional economics stay at an abstract level which is independent of the specific technological and institutional context.

Ronald Coase encouraged his fellow scholars to study ‘the economics of positive transaction costs’ [20]. In our interpretation this encouragement is not only about developing new theories. It is also an encouragement to examine actually existing economic institutions and attempt to understand their working in concrete cases. As a superstructure to such contextual studies, general insights may eventually arise which can be developed in dialogue with the detached theoretical traditions. This approach should also be seen in the perspective of Elinor Ostrom’s work that has demonstrated the variety of actual, empirical institutions which has evolved. Thus, the specific is the general.

To our knowledge, the literature on institutional innovation in the context of developing integrated, 100 % renewable energy systems is rather scarce. This is perhaps not a surprising observation insofar that thinking in terms of 100% renewable energy systems may not yet have become a habit everywhere and somewhere not even accepted . Our view is that the technical feasibility of such scenarios is sufficiently documented, and the scholars whose interests concern the economic and institutional level of energy systems should begin to take point of departure in these technical learnings [15][8].

This paper is an early and humble attempt to start an important institutional innovation process in which the literature strive for using existing technical knowledge to define and formulate new institutional models and expose the properties of those concepts through systematic analysis. The vast majority of the rich and inspiring literature in the field of institutions and renewable energy deviates from the present work by either being working only at an abstract level , focusing on single subsectors of the energy system and/or not sharing the ambition of formulating applicable institutional concepts linked to concrete technical scenarios.

We therefore believe that although the analysis necessarily must take point of departure in the specifics of the Danish system, as explained above, its substance is of wider international relevance.

The Current Empirical Development: What is the problem?

As outlined in the introductory section, the possibility of the ideal technical scenarios is well documented. Meanwhile, the empirical development so far deviates significantly from such technical paths.

While the capacity of wind turbines has continuously expanded in recent years, Denmark has not been moving particularly quickly from a smart energy system perspective. The analysis here will focus on the major challenges surrounding Danish district heating.

In the technical scenarios referred to above, the heating sector is a major recipient of electricity as a wind energy carrier. The volume of the Danish heat market in 2016 is around 55 TWh/year [8]. It is expected that the heat demand in future energy systems will remain of a considerable size. Although renovations and new low energy buildings are expected to reduce overall heat demand, the energy savings potential is delimited by a projected increase in total building area and residual hot water demand [21]. The residual hot water demand includes domestic demand for hot water services beyond space heating. Most future energy scenarios for Denmark assume a heat demand of between 35-40 TWh in 2050 [8] [15][22]. The heat market therefore holds a long term potential as a receiver of wind energy, and should be expected to represent an important part of a smart energy system.

In order to realise the potential synergies through integration of the heat and electricity sectors, investments in heat pumps are needed as this technology that can link the two sectors. The latest statistics from the Danish energy sector do not suggest that these investments are taking place.

While the capacity of heat pumps has been more or less steady at a very low level for the last 10-15 years, the use of biomass resources has dramatically increased [23].The increased use of biomass for heating is problematic for a smart energy system in two ways. Firstly, it does not deliver the needed technical interface, which could promote the integration of wind power and heat production. This integration is necessary to reduce the energy system's overall fuel consumption. Secondly, it consumes a resource that is expected to have a higher value for alternative uses in future energy systems, especially for transport [10][9]. Biomass should also be expected to have important applications outside the energy system. Likewise, land scarcity has been highlighted as a serious challenge for Danish planning in the coming decades [24]. Overall, minimising biomass use for electricity generation and heating should be of high priority in a renewable energy system.

The data also show that heat production is moving from natural gas based combined heat and power plants (CHP) to boiler units, which further decreases the system's overall fuel efficiency [23][25]. The reduced number of operating hours for the CHP units is to be explained by the declining price levels at the Nordic electricity exchange (known as Nord Pool Spot). The average electricity market price in Denmark has decreased 55 percent from 2010 to 2015 [26]. The decrease in price level should, on the other hand, improve the competitiveness of electricity-to-heat conversion. However, as mentioned above, the CHP-units have to a large extent been replaced by boilers --especially biomass boilers.

The reason for this fuel inefficient development can be traced back to the tax structure that surrounds the Danish district heating companies. The tax structure, in particular, represents an institutional barrier for entering the next phase of technological transition.

Table 1 shows the current taxation of electricity and biomass inputs to district heating in 2015. The numbers reveal a clear inequality in the taxation of biomass and electricity. This inequality encourages district heating companies to make investments in biomass boilers at the expense of heat pumps. As such, the present tax structure distorts the allocation of investments in the Danish district heating system.

Input	**Electricity**	**Straw**	**Wood Chips**	**Wood Pellets**
Tax, EUR/MWh	51	1.75	1.15	2.61
PSO, EUR/MWh	34*	0	0	0
Total, EUR/MWh	85	1.75	1.15	2.61

Table 1: ***Tax and PSO payments for competing inputs to district heating.*** **The indicated PSO payment is for late 2015 (PSO is an abbreviation of Public Service Obligation which finances the feed-in tariff for wind turbines, among others.).*

Historically, high taxation on electrical input to the heating sector has been justified by a domestic electricity supply dominated by coal fired power plants. At the same time, the taxation has been rational in order to promote combined heat and power generation and investments in collective heat networks. As wind power capacity is expanding, the taxation on electricity should be adjusted accordingly. This tax policy inherited from the fossil era results in misallocations between biomass and wind as illustrated in figure 1.

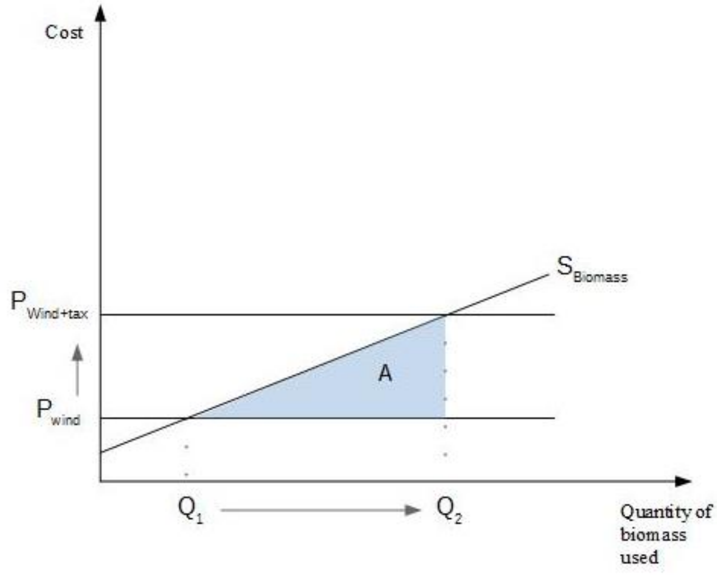

Figure 1 ***Use of biomass as input in the heat market.*** *The figure illustrates the distortion in input factors to district heating caused by the current taxation scheme. The total economic loss caused by the taxation is equal to the area shaded area A.*

When considering input factors to district heating, the tax structure results in an over consumption of biomass compared to wind energy.

Figure 1 illustrates the economic principle that determines the allocation between wind and biomass. The amount of biomass used is found in the intersection between the input factors' costs represented by the curves (keep in mind that these curves are only simplistic representations intended to illustrate the mechanism). The market efficient use of biomass is the quantity (Q_1) found in the intersection between the biomass supply curve ($S_{Biomass}$) and the wind price excluding tax (P_{Wind}). Considering the cost curves depicted in Figure 1, this would mean a low share of biomass input into the district heating sector. However, when the empirical tax structure is added, the market will utilise a biomass quantity (Q_2) found in the intersection between the biomass supply curve and the price of wind including taxes ($P_{Wind+Tax}$). The district heating sector is thus encouraged by the taxation scheme to use larger amounts of biomass than is societally optimal. This misallocation brings about higher system costs and a socioeconomic loss. The size of this loss is equal to the area A in the figure.

In a renewable energy system, it is of vital importance that the finite biomass and the fluctuating wind resources are allocated efficiently. In a market based economy, this would as minimum require a neutral taxation structure. The existing institutional structures are shaped by the past production basis. For example, the high taxation of electricity for heat purposes has been rational in the context of coal fired power plants and the wish to promote combined heat and power production. Likewise, the high taxation of electricity consumption has incentivised energy efficiency, including the build-up of district heating infrastructure.

Since the current tax structures are fitted to the fossil era, it requires institutional innovation to unlock the technical potentials found in a renewable energy system. This paper will propose a new institutional concept developed for the purpose of promoting and supporting the efficiency potentials found in the technical literature. We will focus only on the use of excess wind power and its integration with the Danish district heating sector. However, although the proposed concept is developed on basis of the Danish district heating case, it is intended for wider use. The competition between wind and biomass is a permanent allocative challenge in a renewable energy system. The importance of an efficient allocation between fluctuating wind and solar resources on the one hand, at the easy storable biomass resources on the other, will also arise in the transport sector. This will likely not only include battery electric cars in competition with biofuels. Also the biomass economising electrofuels would require a non-discriminating tax structure in order to prevail.

The institutional concept presented in this paper therefore addresses a fundamental allocative issue in renewable energy systems. If the institutional structure fails to support such resource efficient allocation, the realisation of a fossil free energy supply could become unnecessarily costly if not even hindered.

An electricity tax model for a renewable energy system

Based on the general allocative challenges outlined above, the tax concept must meet two basic criteria. The purpose of the tax concept is to serve the allocative priorities derived from the technical literature. The criteria thus serve the purpose of internalising the techno-economic value of technologies that can act as a flexible infrastructure for large shares of renewable energy.

Criterion 1: It must establish parity between wind and biomass as primary resource

The first criteria can be made either by raising taxes on biomass resources or by lowering taxes on wind energy. A tax on biomass for heating purposes has earlier been tried implemented in Danish politics. However, this attempt failed politically—apparently due to the challenges of monitoring the use of biomass; a resource which, despite its long term scarcity, is widely accessible and almost behave as if it was a quasi-common good and therefore lacks perfect excludability .

Criterion 2: It must be able to differentiate between wind based electricity and fossil fuel based electricity

The second criterion is complicated by the fact that the use of electricity as intermediary energy carrier is a technical necessity. However, the heterogeneous energy resources are not physically separable once fed into the electricity grid. The energy content in fossil hydrocarbons and wind becomes physically homogenous on the electricity demand side and therefore inseparable. A selection proxy is therefore needed if tax reliefs on electricity should be directed towards wind energy only.

Besides adhering to the two design criteria, the concept must also create the right incentives for the central actors in the economic system. First and foremost, this concerns the investment incentives at the district heating company level. Further, the effect on tax revenue is also of interest. The state is a central stakeholder being simultaneously enforcer of taxation and receiver of the fiscal transfers. The designed concept will therefore be evaluated by quantifying its effect on both private economic competitiveness as well as tax revenue.

The proposal put forth in this paper is to implement a tax rate on electricity which is dependent on the hourly share of renewable energy in the electricity generation mix. In the Danish case, this would primarily be the hourly share of electricity generated from wind turbines and, to a lesser extent, photovoltaics. Hereafter we will primarily refer to the wind supply but in in principle we refer to both wind turbines as well as photovoltaics. The underlying principle is to assure that taxation on wind and photovoltaics is equal to biomass – without delivering tax relief to coal fired power plants. Hence, while appearing as a variable tax on electricity it is actually a fixed tax on fuels. The designed tax model should create a situation in which electricity-to-heat conversion becomes an economically competitive option given high real-time wind shares, while becoming more expensive in hours when wind supply is low. The latter condition should ensure that the demand for electricity produced from traditional power plants is minimised.

In the reform proposal, the energy tax on electricity is changed from a flat rate to a dynamic rate which varies from hour to hour. Previously, others have proposed a dynamic tax that is dependent on the Nord Pool price, meaning that low prices would result in a low tax and vice versa. The rationale is the assumed negative relation between wind production and price, implying that hours of high wind result in low electricity prices. As such, the market price has been viewed as a proxy for the wind share of electricity supply. The present proposal is different since it does not directly relate to price. It turns out that the hourly relation between wind and price is not sufficiently strong for the purpose. It should be kept in mind that, theoretically, it is the marginal supplier who sets the price; and the marginal plant, after all, does not convey any information about volume. For example, the same type of coal fired power plant might set the price in hours with 90 percent wind power production as well as in hours with 10 percent wind power production. As can be seen in Figure 2, the wind share varies significantly for most price levels; especially in the mid-price level where the majority of hours are located (the average price in 2013-2015 was around 34 EUR/MWh in the west Danish price area).

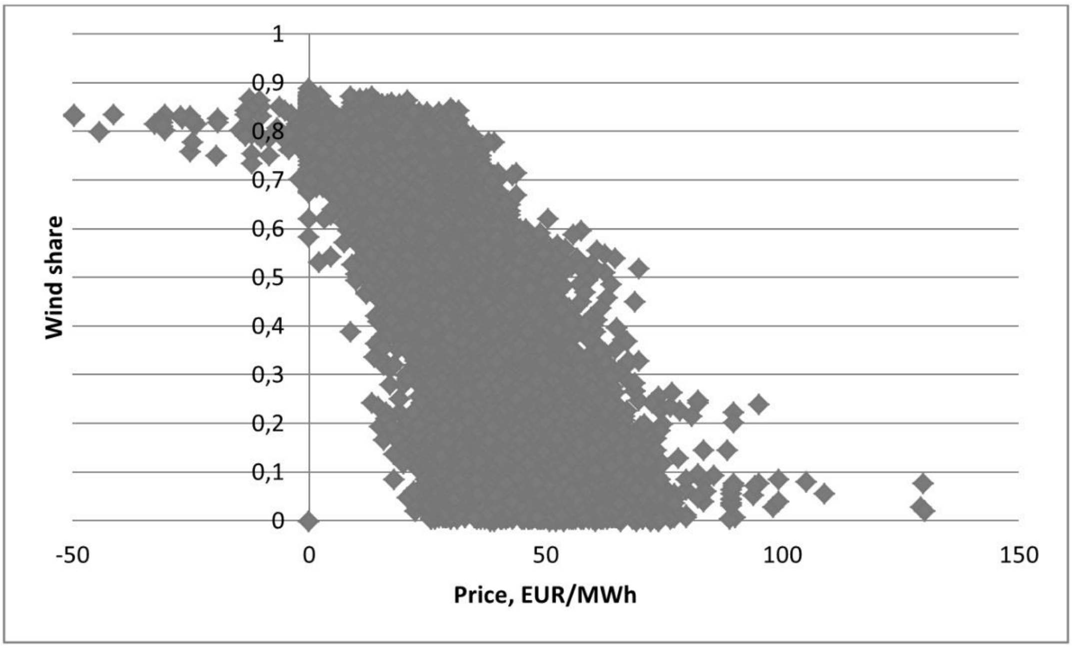

Figure 2: ***The relation between the wind share of electricity production and electricity price****. The figure includes hourly observations for the west Danish price area in the period 2013-2015* [27].

Instead of using the market price as a proxy for wind shares, the present proposal relates to the actual share of wind production in the electricity system. As an example of a concrete configuration, the tax rate starts at today's level during hours with no production from wind turbines (i.e. 50 EUR/MWh). The tax rate will then decline as the wind share increases. In other words, district heating companies would receive a discount equivalent to the share of total electricity production that comes from wind turbines and photovoltaics in a given hour. For example, if 50 percent of electricity generated in a given hour comes from wind turbines and photovoltaics, the tax on electricity in that specific hour would be 25 EUR/MWh (=50-0.5*50). The exact configuration of the tax could be discussed in more detail, but for the purpose of the illustrative calculations in the following sections, this straight forward interpretation is applied. For convenience, this concept is henceforth referred to as a 'smart tax'. The term serves to underline the proposed concept's close connection to the smart energy systems approach.

More generally, the determining factor for this taxation principle could be in one of two formations: either the share of wind power as a portion of the total hourly electricity production, or the share of wind production compared to the total installed wind capacity. The first option, i.e. the share of total production, is chosen so that the tax deduction is based on the wind share of delivered electricity, rather than on the utilisation of installed capacity. A third option is to base the tax on the relation between wind production and consumption. Determining which principle is the most appropriate is up for further discussion. The 'share of production' configuration is chosen to ensure that fossil energy does not achieve green washing through its bundling with wind energy in the electricity grid. If fossil energy achieves higher market shares in the electricity system, the tax will automatically adjust in an upward direction. Moreover, the applied configuration in this paper is based on national aggregation. It could be of interest to investigate other spatial aggregation levels, e.g. wind shares on a more local level. But these questions will not be explored in this paper.

In general, the outlined taxation principle should be perceived as a very pragmatic proposal that addresses the current electricity trade regime. This regime is characterised by a centralised system where the TSO and the Nord Pool electricity exchange constitute a de facto monopolisation of trade in Denmark. Future research should investigate the development of alternative regimes that could compete against this centralised monopoly. Especially, the development of more locally based trade regimes may potentially promote more efficient cross sector integration. However, these questions, regarding the fundamental layer of the institutional setting, are beyond the scope of the present paper.

Quantifying the effects on selected stakeholders

The effect on private economic incentives

In this section, the effect of the tax reform proposal is estimated at plant level. Altering incentives on the private economic level is within the scope of the proposed tax reform, because investment decisions are made at the company level. It is thus of interest to estimate the relative competitiveness of heat pumps compared to biomass alternatives. First, this is done for the current Danish configuration, which includes the distortive institutional structure of taxes and PSO payments. Afterwards, the current setting is compared to an alternative configuration where parity between wind and biomass is established. This configuration includes the ‘smart tax’ concept, described above, and the removal of PSO payments on electricity. The latter is only done to secure parity. Merely removing PSO payments for all resources does not represent a long-term solution to the challenges connected to the PSO tariff. A new PSO design may be required for a smart energy system, but this theme is beyond the scope of the present paper.

Method for estimating the effect on private economic incentives

The exact operating profile of the heat pumps depends on more than just the institutional setting. Also the local technical context would influence the operation of the units. In order to include both contextual levels, the effect of the tax change is investigated by simulating a district heating plant through a whole production year. The simulations have been carried out in the software programme energyPRO. This programme is able to simulate a district heating plant on an hourly basis through a whole production year [28][29].

At the technical level, a reference district heating plant is defined. The reference plant is supplied by a natural gas boiler, a natural gas fired combined heat and power unit (CHP), and a thermal storage unit. As such, it is intended to represent the traditional technological setting for a distributed Danish district heating plant. Four investment alternatives are considered for the reference plant; a heat pump, a straw boiler, a wood chips boiler, and a wood pellet boiler. The effect on the marginal yearly production costs resulting from investment in the heat pump is then compared to the effect from investing in each biomass alternative. The net effect from the heat pump on the yearly heat production cost is thus determined.

The simulations in energyPRO do not include initial investment costs. In comparison with boiler technologies, heat pumps tend to be cheaper in operation but more expensive in investment. A calculated net present value is therefore used as indicator of competitiveness. The net present value of the heat pump is calculated in comparison to each biomass technology by supplementing the yearly savings in operation costs with the investment cost data. The interest rate is set at 5 percent in the calculations. An interest rate of 5 percent may be seen as a relatively low requirement in a private economic environment. The chosen rate reflects the consideration that the relevant companies, being owned by consumers or municipalities, are expected to have a relatively low required rate of return. It should also be noted that current interest rates are relatively modest in contemporary financial markets. A sensitivity analysis using a 7 percent interest rate has been carried out; no changes in the overall result patterns were observed.

In the ex ante scenarios, the institutional configuration is identical to the current. In the ex post scenarios, the taxation is changed from the current to the alternative configuration. Likewise, the PSO payment is removed in the ex post scenario. Based on the scenarios, it can be investigated how the change in taxation would affect the business economic competitiveness of the heat pump. The simulations have been conducted using a 1 MWe heat pump with a COP of 3. For the biomass alternatives, a boiler with an efficiency of 90% is assumed. The latter, especially, is a simplification, as it may not be possible to achieve the same efficiencies for all biomass resources. In Figure 3, the results are summarised.

Results for private economic incentives

Under current regulations, the heat pump cannot compete with any of the biomass alternatives. As seen in Figure 3, the calculations return negative net present values for all ex ante scenarios. However, when the alternative tax regime is implemented, the commercial incentives are turned upside down. The heat pump becomes the most competitive technology in comparison with each biomass alternative, returning positive net present values in all ex post scenarios.

It can thus be concluded that the business economic incentives for promoting electricity-to-heat integration would be in place if the tax and PSO system did not discriminate against wind power as an input resource for district heating. This means that if a sensible tax structure were in place, no subsidies would be needed in this technological area to take the next step towards a 100 percent renewable energy system. A basic principle for avoiding the present discrimination and achieve an efficient allocation has been outlined in this paper.

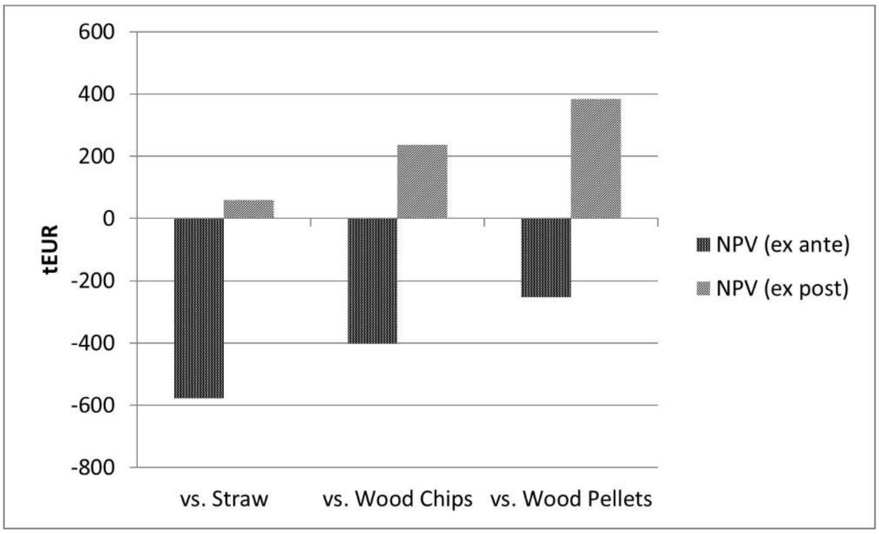

Figure 3: ***Competitiveness of heat pump in comparison with biomass alternatives***. *The figure shows calculated net present values (in thousand euros) for investing in heat pumps compared to three different biomass references.*

The effect on tax revenue

As described in the previous sections, the current tax structure has a significant impact on investment decisions at the plant level. There is also, of course, a receiver of these private economic expenses. The state should therefore also be perceived as an economic stakeholder in contemporary tax structures. Energy taxation has historically played an important role in financing the Danish welfare state. Currently, around EUR 4.5 billion is collected in energy taxation (excluding levies on emissions and vehicles) [30]. It is beyond the scope of the present paper to judge whether or not energy use in general is a favourable subject of taxation from a socio-economic perspective. However, recognising the contemporary role of energy taxation in Danish society, it is relevant to estimate the proposed tax reform's influence on tax revenue.

In general, tax reforms can contribute to the state's revenue in two ways. The first one is direct payments from the tax proposal, i.e. additional tax income received from increased electricity consumption. The other is an indirect effect which is a result of an increase in total economic. This enhanced income may be collected through taxes, thereby keeping consumers' buying power at the status quo; or, alternatively, the resulting increase in consumption would raise the state's tax revenue from VAT, etc. Only the first direct effect is calculated below. However, the second indirect effect should also be expected since a more efficient allocation of wind and biomass would increase total societal income.

Method for estimating effect on tax revenue

The tax revenue has been calculated on the basis of electricity production data from 2014 [**27**]. Similar to when estimating the private economic effects above, an average COP of 3 has been applied. For each input factor, the tax revenue is calculated on an hourly basis and then summarised for a whole year. To determine the contribution from heat pump operation, the tax payment in the biomass scenarios is deducted from the tax payment in the heat pump scenario. Thus, the results presented in Table 2 are the net contribution from heat pumps in comparison with each alternative input resource. The resulting revenue is dependent on how many hours the heat pump is assumed to operate. In Table 2, the results from two selected scenarios are presented: 1) a scenario in which the heat pump capacity is operated only in hours of electricity export (thus interpreting export as a proxy for 'excess electricity'), and 2) a scenario where the heat pump capacity operates as base load. These two scenarios may be perceived as the upper and lower bounds of a possible operating range. How the heat pump capacity would operate in reality would be determined by the exact technical settings and local context.

Results for tax revenue

Looked upon in isolation, the proposed tax reform implies a tax relief on electricity consumption. This relief, however, would not necessarily lead to shrinking tax revenue for the state. This is because the use of electricity for heating could replace the contemporary trend of investing in biomass based capacity. The commercial attractiveness of biomass for heating is, as analysed in the previous section, the result of the current tax structure – and not a reflection of current market prices. Thus, for every MWh of electric input that replaces biomass use in Danish district heating, there would be a non-negative effect on the tax revenue for the state. As an economic stakeholder, the state should therefore have no fiscal reasons for not adopting the tax proposal.

The results show that heat pump capacity of 500 MWe operating as base load could contribute with a yearly tax payment ranging from 85 to over 105 million euro, depending on the biomass resource it replaces (these values are rounded off). If assuming that the heat pump capacity only operates in hours of electricity export, the tax payment would sum up to approximately 30-40 million euros. In a real life application, the operating behaviour for a heat pump, and thereby also the tax revenue, would be somewhere in between the two ranges listed here, depending on the exact technical setting and local context.

	Heat pump operates in export hours only (500 MWe)	**Heat pump operates as base load (500 MWe)**
Replacing Straw	35 MEUR/year	100 MEUR/year
Replacing Wood Chips	40 MEUR/year	105 MEUR/year
Replacing Wood Pellets	30 MEUR/year	85 MEUR/year

Table 2 ***Net tax revenue compared to biomass alternatives****; Tax revenue from a 500 MWe heat pump capacity operating under the smart tax regime. As the lower bound, the revenue is calculated based on the assumption that only exported electricity is redirected into the district* heating sector. As a higher bound, the revenue is calculated based on the assumption that the heat pump capacity operates as base load.

The tax revenue gain also reflects the fact that fossil fuel based electricity would find its way into the electricity-to-heat conversion pool. As the installed renewable production capacity increases in the coming years, the average tax measured in EUR/MWh should be expected to decrease. In order to preserve the total tax revenue at a level that is comparable to the contemporary situation, it would be necessary to raise the 'floor' of the tax on electricity along with the expansion of wind capacity, For example, the tax on electricity may vary from e.g. 15-65 EUR/MWh or perhaps 25-75 EUR/MWh (replacing the current range of 0-50 EUR/MWh). This could be done to the extent that the taxation of biomass is adjusted accordingly, so that energy from wind turbines and photovoltaics is not discriminated in the conversion sector.

Conclusions

The current tax structure in the Danish energy system prevents the most technically and economically attractive developments from being realized. This paper has focused on the institutional interface between the Danish electricity and district heating sectors. The present tax structure is found to explain an unfortunate, empirical development. The tax structure pushes investment decisions into biomass based solutions. These investments result in aggregate economic losses, implying an under-utilisation of electricity and an over-utilisation of biomass.

It is thus clear that the current tax structure must be redesigned in order to unlock the synergies of alternative electricity allocation. To this end, a basic principle for electricity taxation is presented which secures parity between wind and biomass. It is proposed that the electricity tax should be based on the hourly wind share of total electricity production.

The developed alternative tax proposal is designed to secure an even taxation of biomass and wind. In the future, it may be necessary to introduce a higher taxation on biomass. In such a case, the tax on electricity could be adjusted accordingly. However, the inherent variable nature of the proposed tax concept may be worth keeping as it stimulate to flexible demand. Flexibility is valuable in a system with fluctuating supply; not only for heat purposes but also in other conversion activities such as electricity-to-gas.

Besides securing parity in principle, the effect of the tax proposal is investigated in two aspects. The first aspect is the effect on economic incentives for a typical Danish district heating plant. The second aspect is the possible effect on the state's tax revenue. These investigations conclude that 1) the institutional changes will improve the private economic competitiveness of heat pumps to such an extent that they may become more attractive than the biomass alternatives. As such, the commercial incentives would reflect and induce a system beneficial development. In addition, 2) the promoted heat pump installations under such a tax regime would result in increased tax revenue for the state compared to the current regime which promotes a biomass based district heating sector.

As always, price signals through market and tax structures are necessary but may not be sufficient to achieve desired outcomes. The exact effect of the proposed tax concept will be dependent on the contextual planning regimes and hierarchical structures. For example, it is important that the heat pumps do not completely undermine the economic viability of the CHP capacity that is needed in hours of low wind. This is likely to happen if the tax proposal is not accompanied by supplementary regulation. A possible supplementary regulation is to offer the taxation scheme only to district heating companies if they maintain their CHP capacity. Alternatively, the CHP capacity could be sustained through the PSO system. As the PSO payments finance the expansion of wind power, it could also finance the CHP capacity necessary to sustain a wind based electricity supply.

Principles for a future Public Service Obligation tariff have not been specified in this work. It has only been assumed that parity is also established between heat pumps and biomass in this area. The PSO payment on electricity consumption in Denmark is 34 EUR/MWh as of late 2015, and therefore constitutes a significant economic factor. The PSO tariff is used for financing the build-up of wind power capacity in order to supply all energy demands—not only electricity demand. Assessed in this perspective, it could be discussed whether wind power capacity should be financed exclusively through electricity consumption. This is an area that should be subject to further investigation but has been beyond the scope of this paper. Future research should look into new models for financing the PSO. This should be done so that it does not distort the conversion sector in an unproductive way. At the same time, it is important that energy consumers retain the responsibility for all costs associated with energy consumption in order to preserve the allocative balance between investments in production capital and energy savings.

The conclusions from the present case study should motivate similar investigations in other countries. It should be examined whether a comparable faulty institutional structure is present elsewhere. This becomes more important as stored fossil fuels are replaced by fluctuating renewable energy supply. If an efficient allocation across energy sectors is hindered during this transition, it may result in severe misallocation of invested capital in the years to come. Thereby, it would make the transition to a renewable energy system unnecessarily expensive.

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