Mapping public regulation measures for photovoltaic technologies

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ABSTRACT

There is a relatively large potential for the use of photovoltaic (PV) technologies in the Nordic countries, including Denmark. Optimally designed PV support policies are a main prerequisite for the utilisation of this potential. The paper provides an overview of the main (financial) public regulation measures to support PV development. Danish PV development is described briefly and the current Danish PV support scheme is presented and discussed in relation to some of the challenges of PV development. It is suggested that while Danish PV development seems ready to exit the demonstration phase and to enter the diffusion phase, the current net metering scheme may actually not be appropriate to facilitate such a transition.

1. INTRODUCTION

Denmark has been relatively successful in promoting renewable energy technologies, such as wind power, as well as efficient energy solutions, such as district heating CHP (combined heat and power), in the past. Active, supportive policies, open and democratic technology development and ownership as well as the advantage of being a "first mover" were among the main conditions for this successful development [1-3]. The development has also contributed to the creation of export markets for Danish companies, especially for wind turbine manufacturers. By setting the national long-term goal of fossil fuel independence by 2050 the Danish state has recently opened up for continuing such successful development [4]. While the use of direct solar energy is not a major part of these plans (yet), the annual photovoltaic (PV) resources in Denmark are similar to the ones in the Central European countries [5]. The Danish Energy Agency estimates the theoretical technical potential for PV to be in the order of 17 TWh, which corresponds to around half of the current Danish electricity consumption [6]. At the moment, however, only a minor share of the total potential is utilised. Compared with the more than 3,000 MW of installed wind power capacity, the total installed PV capacity of 7 MW in Denmark seems negligible [7]. This figure is especially modest in comparison to other European countries. While the Danish per capita installed PV capacity is 1.3 W, it is 26.4 W in Slovakia – a country with roughly the same number of inhabitants as Denmark [8] (see also Figure 1).

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EU	Market 2009 [MW]	Cumulative 2009 [MW]	Market 2010 [MW]	Cumulative 2010 [MW]	W/inhabitant
Austria	20	53	53	103	12.6
Belgium	285	379	424	803	73
Bulgaria	5	7	11	18	2.4
Czech Republic	398	463	1490	1953	191.5
France	219	306	719	1025	15.5
Germany	3806	9785	7408	17193	211
Greece	36	56	15	206	19.3
Italy	717	1173	2321	3494	60.2
Portugal	55	114	16	130	11.5
Slovakia	0	0	145	145	26.4
Spain	17	3415	369	3784	80.5
United Kingdom	10	21	45	66	1.1
Rest of the EU	50	235	98	333	

Figure 1. Installed PV power capacities in a number of European countries (source: [8])

Successful renewable energy policies in countries like Germany, Italy and Spain have contributed to continuously growing PV markets in Europe, which in turn have lead to significant cost reductions during the last years. PV costs have decreased by nearly 50% in the last decade and the European PV industry expects current average PV system costs of around 3-4 €/Wp to decrease by at least 35% until 2020 [9]. Thus, the attractiveness of PV investments is increasing further – also in the Scandinavian countries. This could, for instance, mean that alternative solutions such as the concentration of large-scale PV installations in North Africa could become unattractive, considering the extra transmission costs involved. Furthermore, a "North African solution" would not result in regional socio-economic benefits, including job creation, increased self-sufficiency in the energy supply and improved efficiency of local electricity distribution grids [7,10]. Apart from that PV can potentially fit well into the Danish future wind-based energy system, due their somewhat complementary load profiles. Recent research concerning 100% renewable energy systems for Denmark concludes that PV can play a substantial role in such systems. According to CEESA (Coherent Energy and Environmental System Analysis) PV can contribute with 6-12 TWh of electricity production in the Danish system and can be integrated in the system together with substantial amounts of wind power, resulting in 70-80 per cent of the electricity demand covered by wind and PV[1]. It is therefore necessary to investigate possible public regulation measures that can accelerate PV growth in Denmark.

In the paper, this is approached in the following way. PV development is first put into a theoretical perspective on renewable energy innovations. The particular characteristics of renewable energy innovations compared to other technological innovations are discussed and the significance of these characteristics for the design of appropriate public policy measures is

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[1] This research on 100% renewable energy systems builds on scenarios conducted in Mathiesen et.al [11].

sketched. Secondly, main PV support mechanisms are identified based on a review of relevant international literature. In the subsequent section, the Danish PV development is described with a focus on the current public regulation measures. Possible implications of the Danish PV support scheme for Danish PV development are then discussed.

2. PV SUPPORT MECHANISMS

Public regulation measures are one way to steer technological innovation and development. In this section, the significance of public regulation measures is first discussed in relation to renewable energy technology innovation. Then, an overview over the main public regulation measures for PV technologies is presented.

2.1 Theoretical background on renewable energy innovation

Technological innovation is often divided into the three phases of *research & invention*; *testing & demonstration*; and *diffusion* [cf. 12,13]. During the first phase, knowledge about new technologies is created on the "laboratory level" in research institutions and companies' R&D departments. It involves the creation and testing of (small-scale) prototypes and thus, an internal process of "becoming familiar" with a new technology. Next, a second (parallel) step is added to the innovation process, during which the new technology is tested on a larger scale. In case of renewable energy technologies, such testing may involve the demonstration of the technology outside the context of the research institution; i.e. in "real life". During this second phase the new technology is prepared for market introduction. Once the new technology can compete with other existing technologies a wider diffusion of the new technology in society can begin in the third phase. While all three phases are crucial to the innovation process, much of the recent literature indicates that the transition from the testing and demonstration phase to the diffusion phase is especially critical, as it often requires substantial political and societal support [14]. Jacobsson and Lauber [14] have characterised this transition or maturing process as being conditioned by institutional and regulatory changes that are influenced by technology-specific advocacy coalitions. The goal is the formation of new markets that supports and is accompanied by the entrance of new firms and organisations. It is in this regard emphasized that the formation of early, protected niche markets is important for the technological learning process (in the demonstration phase) [15]. At the same time, it seems to be crucial that early market formation is followed by the creation of larger markets in which a rapid diffusion of the new technology can take place. In the case of renewable energy, stable economic support has been identified as important factor to achieve the cost reductions that are necessary to initiate this rapid growth phase (16,17]. The focus on further cost reductions seems to be especially crucial in case of PV, where initial costs still are higher than for other renewable energy alternatives [16].

While economic stability for investors is an important success factor during the market formation phase, it is not the only one. It has been shown that efficient administrative processes are at least as important as financial stability [17-20], and that long and complex administrative processes can be a significant barrier to a rapid deployment of PV technologies [21]. Furthermore, the level of financial support should be sensitive to the pace with which domestic renewable energy technology manufacturers are emerging. In the case of Germany it has been suggested that unusually high financial support has led to a rapid increase in the demand for PV, which could not be met by domestic manufacturers. This has led to a situation where nearly half of the PV modules installed in 2006-2007 were imported from Asia [22].

It is furthermore important to note that renewable energy innovations can often be considered "system innovations", as their implementation/diffusion requires or leads to changes in the surrounding energy system [23]. For example, due to their distributed and intermittent character, the implementation of renewable energy technologies will also have to entail modifications in existing energy systems, in terms of increased flexibility and integration. Furthermore, since the value chain and operational profile of renewable energy technologies fundamentally differs from traditional energy technologies, new actors, organisations as well as institutional frameworks are required to ensure their implementation. This will also have to entail a change in existing cost structures – the internalisation of external costs into energy prices, for instance – so as to reflect all (potential) benefits of renewable energy. The need for new knowledge, organisations, institutional frameworks and market practices turns renewable energy innovations into complex technological innovations that cannot be expected to happen automatically and from within existing technological and institutional structures. The experiences with especially wind power in Denmark, Germany and other countries indicate that the transition from the demonstration phase to an actual, self-propelled diffusion phase requires longer-term and more continuous support measures than in case of other (simpler) technological changes. It could therefore be proposed to add a fourth phase to the technological innovation process that is discussed above. This phase could be termed *"formation of a national market"* and would be the third phase, leading up to the diffusion phase, acknowledging that even if PV technology is able to compete technically, there could be institutional, financial or technical system barriers that hinder a wider diffusion. Thus, internal and external prototype testing & demonstration takes place in the second phase, whereas the large-scale demonstration and implementation of the renewable energy technology takes place in this market formation phase.

It can also be added to the above discussion that the complexities and system interactions related to PV development will increase, once PV technologies are seen as part of the technological change of the whole energy system. The need for electricity demand reduction as well as balancing and integrating power loads, will require (regulatory) support mechanisms that do not only focus on the expansion of production capacities for wind, PV etc. It will be necessary to develop support mechanisms that balance energy supply and demand.

2.2 Overview of main PV support mechanisms

In order to facilitate the transition from testing and demonstration to market maturity (at least) four main barriers have to be overcome: i) high initial costs; ii) administrative barriers and long planning permission procedures; iii) difficulties in gaining priority access to the grid; iv) lack of public acceptance and support [17,20,24]. The first barrier, high initial costs, will be the main focus in the following sections, and also seems to have been widely discussed in literature so far, not least because several countries have approached this barrier in different ways. Table 1 provides an overview of the main regulatory mechanisms that have been applied in overcoming this barrier. The main goal of these mechanisms is to increase the market for PV technologies and thereby accelerate cost reductions. The table is based on a review of international studies concerned with PV support mechanisms [14,17,19,21,24,25-30].

Table 1. Overview of main regulatory mechanisms for cost reduction and market expansion of PV technology

Policy measure	Description
Feed-in tariffs (FIT)	- a publicly set tariff, which is paid by utilities to grid-connected PV producers in their supply area - FIT costs are usually distributed across the utility's customer base in the form of e.g. increased electricity prices - FITs can very according to solar resource conditions in

	order to stimulate PV investments in the whole country - FITs can take the form of price supplements, where the FIT varies according to the market price of electricity, but where the sum of FIT + electricity price is fixed
Tradable Green Certificates (TGC)	- Certificates for the production of a certain amount of renewable energy - Can be traded between energy producers on a TGC market - Are based on publicly quantified renewable energy targets (quotas) - The price of the TGCs depends on their amount; i.e. their price decreases with increasing numbers of TGCs on the market, meaning energy producers are closer to fulfilling their quotas
Net metering	- PV owners only pay for their net electricity consumption; i.e. fed-in electricity and electricity bought from the utility have the same financial value - allows PV owners to “store” the produced electricity in the grid and use it at a later point in time - -Net production can sometimes be accounted with a FIT
Capital subsidies	- Direct subsidies: (A share) of the PV investment is (publicly) funded - Indirect subsidies: Can take the form of low-interest loans (e.g. the German 100,000 Roofs Solar Power Programme)
Tax credits	- Production tax: tax break on the electricity sold to the grid - Investment/installation cost tax: tax deduction on investment and installation costs - Lower VAT on investments

Besides FIT models that take regional resource variations into account, some countries have introduced a gradual reduction of the FITs to stimulate cost reductions over time. It has been suggested that especially these “advanced” FIT models [31] are more effective in supporting growing renewable energy markets than TGC models based on a green certificate market [23, 32, 33]. In fact, out of the 17 “western” European countries, 15 have adopted FIT schemes, among which are the countries with the largest numbers of installed PV capacities, i.e. Germany and Spain (see also Table 1) [21]. On the other hand, actual cost reductions for PV production and installation may well be larger than the fixed annual reduction of the FIT in the German model [22]. For this reason, FIT reductions might have to be adjusted annually to the rate of cost reductions.

Regarding the other support mechanisms, Dusonchet and Telaretti [21] found that capital subsidies and tax credits are no longer used as main policy instruments in the 17 western EU, but mainly as supplementary instruments in conjunction with other mechanisms, such as FIT and TGC. However, as described by Jacobsson and Lauber [14], PV investments in Germany slowed down significantly after the phase-out of low cost loans under the 100,000 roofs programme, and besides the introduction of higher FITs. As described in the next section, net metering can still be considered the main support mechanism for PV in Denmark, but has, for instance, also been applied in California [26].

The existing literature furthermore indicates that the set-up of the support mechanism and its combination with other support mechanisms can impact PV market development significantly.

Financing FITs through a (limited) public budget, for instance, seems to have an inhibiting effect on PV development, while financing FITs through customer's electricity bills does (in theory) not put a cap on PV development [21]. Combining FITs with a nationally set installation target/cap can also have inhibiting effects, especially if the target is approached quickly or set too low [14]. Thus, just as for other renewable energy technologies [cf. 18], clearly defined long-term policies and mechanisms, instead of "stop-and-go" policies, seem to be a crucial criteria for PV development.

2.3 Status of PV development in Denmark

PV development in Denmark officially started around 1992 when the Danish Energy Authority began commissioning a number of status reports and actions plans on PV technology [13]. One of the main actors during this start-up phase was the utility company EnergiMidt (formerly EnCon), which began testing and demonstration of grid-connected PV roof-top systems in 1993 [34]. Until 1998 this involved mainly small projects, which received funding from the Danish Energy Agency and two electricity companies. Between 1998 and 2001 EnergiMidt implemented a larger project, SOL-300, which was financed through public service obligation (PSO) funds and involved the installation of 300 PV roof-top systems. Around 750 kW of PV capacity were installed and with a focus on installation prices a price reduction of around 20% was achieved during the project period [34]. The SOL-300 was in 2001 upgraded to the SOL-1000 project, which together resulted in 1,000 PV roof-top installations with a total capacity of around 3 MW [35,36]. EnergiMidt has thus been the main driving force in Danish PV development so far, having installed around 1,300 PV systems out of the currently around 1,500 installations in total [37,38]. Besides a reduction of installation costs these demonstration projects have (indirectly) led to the establishment of a national quality assurance system for solar cells and the formation of competence networks, such as the Danish Solar Cell Association. Up until now the Danish PV development can be described as going through an "introduction and demonstration phase" [13], which was similar to the experiences from countries like Germany, but which has not yet been taken to the "diffusion phase" [cf. 39,40].

Denmark is one of the few western EU countries, which currently does not support PV development through either FITs or TGCs [21]. Instead, grid-connected PV installations smaller than 50 kW are supported by a net metering scheme [41][2]. According to the scheme, owners of such installations can choose "net accounting" for the electricity produced by the PV installation. This means that PV-based electricity exceeding the current electricity demand at the site of installation can be "stored" in the grid and can be consumed at a later stage at a cost of zero. Net excess electricity delivered to the grid will be compensated for by the TSO with 0.08 €/kWh consisting of a fluctuating spot market price for electricity and a price supplement during the first 10 years. During the following 10 years this fixed payment amounts to 0.053 €/kWh, after which only the spot market price is paid. In case the annual amount of electricity consumed exceeds the electricity produced at the PV installation, the difference has to be paid for at the normal cost of electricity. On the other hand, both, private and commercial installations are exempt from paying PSO taxes and the usual price supplement for environmentally friendly electricity for consumed electricity that has been "stored" in the grid [42]. In addition, private installations smaller than 6 kW are exempt from paying an electricity tax for the amount of electricity consumed that is below the amount of electricity produced at the PV installations, hence at a cost of zero [43]. In the Danish net metering scheme, renewable energy installations can fall into one out of six

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[2] The Executive Order also includes wind turbines with a capacity below 25 kW and micro-CHP units with a capacity below 11 kW.

"accounting groups", out of which groups 4-6 apply to PV installations [42]. Table 2 contains an overview of the three accounting groups, based on [42] and [44].

Table 2. Overview of those groups in the Danish net metering scheme that apply to PV installations designed for own production

Net metering group	Description
4) Commercial PV installations < 50 kW, selling electricity production to TSO/spot market	- Net excess electricity production is sold to the TSO (spot market price + price supplement) or on the spot market - No PSO tariff has to be paid for electricity from the grid, and no payment of reduced PSO tariff for fed-in electricity
5) Commercial PV installations, not selling electricity production to TSO/spot market	- Own production is defined as the total net electricity production; All/most PV production is consumed directly on-site - Electricity fed into the grid is not measured and delivered to the DSO/TSO at a price of 0 - The producer has to pay a reduced PSO tariff for electricity fed into the grid - No capacity limit on PV installations
6) Private PV installations	- Electricity grid acts as storage of excess electricity production - Applies to installations below 6 kW per private residence or below 6 kW per 100 m2 roof area for public buildings - Net delivery to electricity grid is not traded at the spot market, but regarded as balancing/grid loss reducing contribution - Net excess electricity production is accounted using the spot market price + price supplement (FIT) model (0.08/kWh)

It should be noted that PV installations larger than 50 kW can also make use of the net metering scheme, but will have to pay a reduced PSO and grid tariffs [44]. The Danish TSO Energinet.dk is furthermore setting up a register for all PV installations applying for the net metering scheme.

In 2011 the Danish Government launched a 3-year programme to promote domestic services and refurbishment of homes [45]. According to the programme, installation costs for energy-efficient refurbishment and PV systems, for instance, are entitled to be deduced from taxes. The maximum amount to be deduced is around 2,000 €/person/year.

3. DISCUSSION

From a technological innovation perspective, Danish PV development can be regarded as having undergone the testing & demonstration phase, however, without entering into a market formation or "take off" phase. This is remarkable, considering that the Danish "roof programmes" helped build industry networks and could even document cost reductions of around 20 % [35]. The formation of the Danish Solar Cell Association, the introduction of a quality assurance system and the identification of industrial strengths within crystalline silicone production, for instance, [13] seem somewhat similar to what characterised Danish wind power development. PV development has, however, suffered from its position as a "late comer" that did not benefit from the same public support schemes as wind power in 1980s and 1990s. And after 2000, no PV support scheme, similar to the one for wind power, was set up. Therefore, it seems that large-scale PV development was not initiated at a point, when PV technology otherwise was "just about ready" for a national market formation phase. One reason for this might be that at this point in time the new government, which came into power in 2001, had just implemented significant cut backs on renewable energy support in general, which for instance brought wind power development to a halt until around 2008 [18]. This underlines the critical importance of stable support schemes for successful renewable energy development.

Support schemes involving FITs have proven to be the most effective in promoting PV development so far. To what extent the Danish net metering scheme can boost PV development remains unclear. Further research will have to focus on the project- and socio-economic effects of this scheme compared to an (advanced) FIT scheme, for instance. For the moment, the effective payment of around 0.27 €/kWh, corresponding to the average Danish costs of electricity, is slightly below the lowest FITs paid in other European countries [21]. In the medium term (~5 years) this seems reasonable, as other European FITs will be decreasing to around the same level. However, in the long term, the scheme may prove to be too static and lead to "overcompensation" for PV production, as the effective payment does not decrease with improved technological learning and increasing cost reductions as in advanced FIT schemes. It can therefore be recommended to investigate the shift towards and advanced FIT scheme for PV would be appropriate (in the long term) in Denmark. Since all PV installations under the net metering scheme have to be registered, technological progress and cost reductions could be monitored on a national scale. This would seem one good prerequisite for initiating an advanced FIT system in the future.

Furthermore, it remains unclear if the 6 kW / 100 m^2 limit for non-commercial installations is appropriate in relation the PV capacity needed in the energy system in the long term. The 6 kW limit corresponds approximately to the electricity consumption of 4,000-4,500 kWh/year in an average Danish household with 4 persons. Currently, there seems to be also some demand for 6 kW installations or larger in households with a higher than average electricity consumption. Such households may usually have a heat pump and therefore an interest in offsetting that extra electricity demand. Apart from that, not many households seem to choose PV installations that produce more electricity than the household's demand. This means that the fixed payment scheme provided by the TSO would currently not seem much in use [46]. The fixed payment of 0.08 €/kWh is also less attractive than the effective payment of 0.27 €/kWh when PV production is higher than the electricity demand. For PV installations that produce less than the demand on an annual basis this means that there is an incentive to save electricity until the point, where PV production matches the demand. As soon, as the demand decreases below the PV production, this incentives disappears because now there is PV excess production which is only compensated with 0.08 €/kWh instead of 0.27 €/kWh. On the other hand, it could be argued that receiving 0.08 €/kWh for the excess production is better than not receiving a compensation at all. However, it seems to be clear that "oversized" PV installations cannot motivate electricity demand reductions.

The experiences from the Danish PV demonstration projects furthermore indicate that a households' electricity consumption can actually decrease by 10% after the installation of PV and the associated electricity meters [35]. This indicates that PV installations can help raise consumer awareness, which would make it seem natural (and necessary) to better link the PV support scheme to the electricity consumption. One way to approach this issue could, for instance, be to implement separate metering for PV production and electricity consumption; i.e. to "decouple" the two. This system is already implemented in other "FIT countries" and guarantees that electricity savings actually result in real electricity cost savings.

4. CONCLUSION

There is a relatively large potential for the use of photovoltaic (PV) technologies in the Nordic countries, including Denmark. Optimally designed PV support policies are a main prerequisite for the utilisation of this potential. In this paper, the crucial importance of a (national) market formation phase for renewable energy technologies is emphasized as a phase during the technological innovation process. This market formation phase is significant because renewable energy innovations typically are complex innovations that involve changes in the entire energy system. This means that a wide diffusion of these technologies will not happen automatically after their technical potential and suitability has been demonstrated. Stable and long-term support policies are more necessary than in case of (simpler) technological innovations. It is shown that, internationally, FIT schemes have proven to be the most successful public regulation measures for renewable energy development and in particular for PV. Danish PV development has been through a testing and demonstration phase and seems to have been ready to enter an actual national market formation phase for at least the past five years. In the past, however, no appropriate PV support schemes have been set in motion, which may be one of the main reasons why no real Danish PV market has formed yet. Apart from that, Denmark is one of the few European countries that have implemented a net metering scheme, according to which PV based electricity compensates for a household's electricity consumption. The next few years will be crucial in deciding if this scheme can actually kick off large-scale PV development in Denmark. Recent trends seem to indicate that there is a significant public interest in small-scale PV installations, but it remains unclear if this development will be sufficient in light of the transition towards a 100% renewable energy system. Moreover, it needs to be clarified to what extent the net metering scheme may hinder the implementation of electricity savings in households.

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