energies

Article

Analysis of the Net Metering Schemes for PV Self-Consumption in Denmark

Helena Martín *, Jordi de la Hoz, Arnau Aliana, Sergio Coronas and José Matas

Electrical Engineering Department, Escola d'Enginyeria de Barcelona Est, Polytechnic University of Catalonia, 08019 Barcelona, Spain; jordi.de.la.hoz@upc.edu (J.d.l.H.); arnau.aliana@gmail.com (A.A.); sergio.coronas@upc.edu (S.C.); jose.matas@upc.edu (J.M.)

* Correspondence: m.helena.martin@upc.edu

Abstract: The current Danish regulatory framework BEK 999/2016 for hourly net settled new PV facilities is analysed in detail, evaluating the technical and economic differences between the several envisioned schemes. In addition to the saved cost of the self-consumed energy, the transmission system operator (TSO) tariffs and the public service obligation (PSO) tax are avoided for the self-consumed energy. Advantages regarding the electricity tax and VAT can also be obtained but according to a more varied casuistry, with a particular incentivizing effect for the residential customers. The installation-connected type group 2 is found the cheaper scheme and the billing concepts responsible for its minor cost are identified. This analysis is expected to contribute to discerning the different economic outcomes of the various schemes, helping to take informed investment decisions. Transcending the local value, some common characteristics of this complex framework that can also be found in other regulations may ease the comprehension of the leverage points and the policy instruments for modulating the economic results of the facilities and in this way also their path of deployment.

Keywords: net metering; net settlement; self-consumption; Denmark; PV; electricity taxes; regulatory framework

check for updates

Citation: Martín, H.; de la Hoz, J.; Aliana, A.; Coronas, S.; Matas, J. Analysis of the Net Metering Schemes for PV Self-Consumption in Denmark. *Energies* **2021**, *14*, 1990. https://doi.org/10.3390/en14071990

Academic Editor: Alessandro Massi Pavan

Received: 17 February 2021
Accepted: 31 March 2021
Published: 3 April 2021

1. Introduction

1.1. Setting the Context

Denmark has been praised for its energy policy enabler of a successful deployment and integration of renewable energy (RE). During the three consecutive years 2016–2018 the performance of its national energy system placed first in the classification issued by the World Energy Council, according to energy security and equity and environmental sustainability criteria [1].

Likewise, Denmark has committed itself to reach net-zero emissions no later than 2050, thus achieving independence from fossil fuels. As intermediate goals for 2030, it has set the targets of supplying 55% of energy consumption and above 100% of electricity consumption with RE [2].

In this sense, as of end 2019 Denmark ranked second among the top five countries with the highest RE power capacity per capita (not including hydropower). Its share of RE in electricity generation stood at 77%, with an increase over 97% in the last decade [3].

Although Denmark is relying mainly on wind power for reaching its goals of electricity from RE sources (RES-E), it is also envisaged an increased share of solar photovoltaic (PV) technology in its power generation mix. Thus, acknowledging that PV will be the cheapest technology in the medium term, a share of 13% in RES-E is considered in the projections for 2030 [2]. Despite the limited global horizontal irradiation (GHI) of around 1000 kWh/m2·year [4], by the end of 2019 the Danish PV capacity was 1079 MW, with 953 GWh of PV production [5] supplying 3% of electricity consumption [4].

The modular character of PV makes it particularly suitable for self-consumption applications, especially for smaller scale systems. In this line, empowering the consumers making them able to generate, store and/or sell their own produced electricity is an identified priority of the European Union (EU) [6].

Denmark pioneered in this field implementing annual net metering with electricity tax exemption at 1999. Since then, several regulatory changes took place, involving the payment to prosumers of a remuneration in the form of a feed-in tariff for their surplus electricity and the exemption of an additional surcharge of the electricity tariff, i.e., the public service obligation (PSO). These improvements in the support scheme, along with the declining costs of PV systems and rising electricity prices, led to a PV boom in 2012. The total installed capacity that year reached 407.8 MW, increasing by more than 2.340% compared to 2011. Around 99% of the total PV capacity by the end of 2012 corresponded to the grid-connected distributed typology [7].

Since around 2/3 of the retail electricity price in Denmark corresponds to taxes, this fast expansion of self-consumption posed a significant reduction of fiscal income for the State. Consequently, a series of new regulatory changes intended to curb the PV deployment were adopted. They included, among others, the shift from the annual to an hourly compensation scheme, progressive reductions in the feed-in tariff level and duration and its final elimination. Currently, the only advantage for new PV prosumers under the Danish net metering scheme is the compensation of self-generation and consumption within an hourly basis, with total or partial exemptions on certain tariffs and taxes. By the end of 2019, the share of grid-connected distributed PV fell to around 70% of the total installed capacity [8], far from the 99% level of 2012.

1.2. State-of-the-Art

The body of academic literature dealing with grid-connected distributed PV facilities in Denmark is scarce. The most frequently targeted type of prosumption is related to 1-family households. Thus, in [9] it is investigated the impact on voltage security and grid loss of the integration of residential solar PV in the distribution grid at the Danish island of Bornholm. In [10] it is analysed the performance of two power and energy management strategies for a residential PV–wind-battery system, for Danish generation and load profiles. In [11] it is shown that households with PV and demand response programs achieve lower electricity costs when exposed to volatile prices of highly developed power markets, as is the Danish case, than in less developed ones, as in the Croatian case. The performance of residential organic PV systems is assessed at Denmark and Greece in [12], determining the influence of their net metering schemes, irradiation levels and matching between production and consumption profiles. The study in [12] is further developed in [13] including battery storage and life cycle assessment. In [14] it is presented the optimal energy management of a residential PV system with battery storage, taking into account the impact of the Danish grid tariffs and negative electricity market prices.

Regarding the analysis of multi-apartment buildings or other types of community residential shared facilities, some other references can be found. Thus, the economics of using batteries in a community PV microgrid system under a net metering scheme is evaluated in Denmark and 3 other countries in [15], finding that the profitability is strongly dependent of the electricity prices and the irradiation level. In [16] it is compared the technical performance of residential PV systems with either individual batteries or a single communal one in the Danish island of Samsø. The status at Denmark and 8 other countries of collective PV systems in apartment buildings is reviewed in [17].

As for non-residential self-consumption applications, the life cycle environmental impact of organic PV systems with battery storage is assessed in [18] for different industry sectors in Denmark. In [19] it is presented the model predictive control based energy management of a PV microgrid with battery storage and controllable loads at the Ballen marina in the Danish island of Samsø. In [20] it is performed the optimal sizing and energy management of a PV-wind-battery storage microgrid for a seaport in Copenhagen.

Most of the former references do not take into account the Danish regulatory framework for PV self-consumption in their analyses. The sole exceptions are [12,13], which expose some general aspects of the Danish PV self-consumption regulatory framework, and [17], which qualitatively compares the main provisions for the collective self-consumption in Denmark with those of other countries. Nevertheless, and up to the authors' knowledge, the current Danish regulatory framework for new PV self-consumption facilities has not been analysed in detail in the academic literature. Even more, the impact of electricity taxation is particularly different in Denmark for the several customer segments and this fact constitutes an indirect incentive for PV self-consumption adoption that still lacks analysis from the academia.

1.3. Contribution

As previously discussed by the authors in [21,22], the consideration of the constraints introduced by the regulatory frameworks in the model of the energy systems may significantly alter their techno-economic outcome.

In this regard, the correct understanding of the different schemes envisioned in the regulatory frameworks for net metering is vital in order to appropriately assess the technical and economic performance of these systems. It may be particularly challenging to adopt informed decisions on the investment and the selection of the most suitable net metering option when the regulations are perceived as complex, fast-varying or even retroactive.

The energy policy for PV net metering in Denmark has experienced several changes in last few years in an attempt to curve the bubble-like behaviour exhibited by these facilities in 2012, which entailed a significant loss of tax income for the State and of revenue for the electricity system. As a result, the varied set of regulations in force for different groups of facilities has been appraised as highly complex, constituting a barrier for the deployment of these systems and increasing the risk for all the actors of the sector [7].

Aimed at filling this gap, the present study analyses in depth the current regulatory framework for hourly net metered, or net-settled, PV facilities in Denmark. The different schemes and their technical and economic implications will be theoretically assessed and also exemplified on a case study.

The possible schemes in the Danish regulatory framework are also considered in the regulations of other countries, as well as some of the Danish billing concepts that have their counterpart in other regulatory frameworks. In addition, being that the Danish regulation for net metering is a highly complex one, its methodical analysis might be helpful for illustrating how to undertake the assessment of other frameworks. For these reasons, the tackled Danish case is worthy of analysis and goes beyond the local value. Additionally, the conclusions raised for the high electricity tax in Denmark can be also applicable for other countries with significant share of taxes in the final price of electricity.

This study is organised as follows. After contextualising the analysis, reviewing the state of the art, identifying the gap in the literature and pointing to the value of the presented contribution in Section 1, materials and methods are considered in Section 2. Thus, the Section 2.1 describes the followed methodology, the Section 2.2 describes the Danish regulatory framework for hourly net-settled new PV facilities and the Section 2.3 introduces the selected case study and all the necessary data. Then, several results of interest are presented in Section 3, which are discussed in Section 4. Particularly, the Section 4.1 analyses in detail the regulatory framework, both theoretically and also relying on the case study results, the Section 4.2 assesses the uneven impact of taxes on the different customer segments, the Section 4.3 points to additional considerations that might qualify the obtained findings and the Section 4.4 envisions future research. Finally, conclusions are raised in Section 5.

2. Materials and Methods

2.1. Methodology

The sequence of steps followed for the analysis of the different net metering schemes for PV self-consumption under the Danish BEK 999/2016 regulatory framework is now described.

First, the Danish legislation currently in force for new PV self-consumption facilities is examined, as well as other related documents issued by official authorities and agents of the electricity market. Then, a feasible case study for illustrating the application of the several allowed net metering schemes is selected.

Next, the corresponding energy and economic cost results are obtained using a spreadsheet. Following, these results are analysed in order to compare the characteristics and performance of each of the possible net metering schemes, and the elements having the higher impact in their outcome are then identified.

2.2. Description of the Danish BEK 999/2016 Regulatory Framework

The current Danish regulatory framework for hourly net settlement was developed by the Executive Order on net settlement for own producers of electricity (BEK 999/2016) [23] and its subsequent amendments [24]. Under this scheme, the producer can obtain partial or total exemption of certain taxes and tariffs for the self-consumed electricity, or heat and electricity.

For the PV case, the plants with rated power above 50 kW ($P_n > 50$ kW) have partial PSO exemption, specifically regarding the surcharge for the support of renewable energy. Likewise, they can be either direct-connected, i.e., located at the place of consumption but directly connected to the public electricity supply (see Figure 1a) or installation-connected, that is, connected to a private supply system (see Figure 1b). On the other hand, smaller PV plants with rated power lower or equal to 50 kW ($P_n <= 50$ kW) have total PSO exemption and must be installation-connected [23].

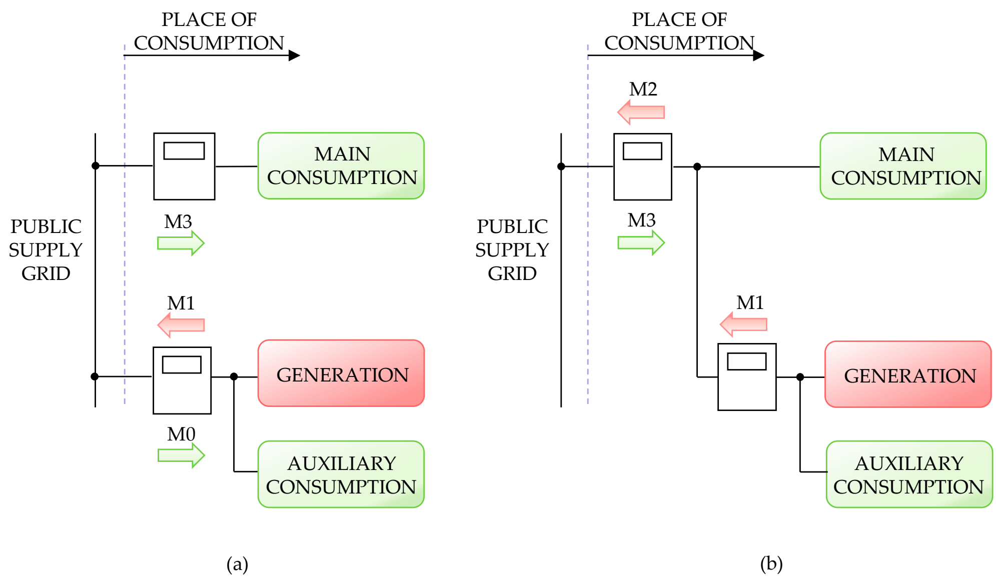

Figure 1. Connection types for net settled facilities under the Danish regulatory framework: (**a**) Direct-connected; (**b**) Installation-connected. Source: self-elaboration.

Currently, new plants approved for entering into hourly net settlement can opt for two different groups. In group 1 all the production is sold, whereas in group 2 it is only sold the surplus production [25,26]. New plants not applying or still waiting for the hourly net settlement approval enter into an instant net settlement scheme, with the same conditions for the total or partial PSO exemption than the hourly net settlement [27]. The above described organizational arrangement for PV hourly net settlement is summarized in Table 1.

Table 1. Hourly net settlement possibilities for new PV facilities under the Danish regulatory framework. Self-elaboration.

Connection Type	Rated Power [kW]	Electricity Sold	
		Group 1: All	Group 2: Surplus
Installation-connected	<= 50	✔	✔
	> 50	✔	✔
Direct-connected	<= 50	✘	✘
	> 50	✔	✔

2.2.1. Metering Points

Figure 1 shows the location of the different physical metering points M0, M1, M2 and M3 envisioned for each of the connection types of the net settled facilities. The metering point M1 registers the net energy production, while the bidirectional meter M2/M3 measures the energy delivered to/obtained from the public supply grid. It must be noted that the metering point M0 in charge of measuring the auxiliary or own consumption of the production facility is not depicted at Figure 1b. This metering point is not required at installation-connected facilities, since the auxiliary consumption is also registered by M3. Additionally, the meter M1 can be dispensed with for group 2 installation-connected PV facilities with rated power lower or equal to 50 MW [25].

Data from the metering points M0, M1, M2 and M3 is read on a 15/60-min basis. Specifically, in Eastern Denmark all the metering is generally performed on an hourly basis, whereas in Western Denmark production and exchange is quarter-hourly metered and consumption is hourly metered. (The Danish transmission network is composed of the Eastern and the Western parts, linked by a high-voltage direct current interconnection. The Danish Eastern transmission network is connected to the Nordic grid through Sweden and Norway, and the Western transmission network is connected to the European continental grid through Germany [28]).

Additional metering points are defined for the net settled facilities, based on the readings from the meters M0, M1, M2 and M3. Table 2 collects these additional metering points and their particular definition for each of the connection types and groups.

The metering points listed at the first two rows of Table 2 are the so-called Net from Network (NFN) and Net to Network (NTN) and they register the difference between the hourly energy received from and fed to the public supply grid and vice versa, respectively. Both NFN and NTN are either positive or null quantities, and can be mathematically determined as the maximum of a specific combination of the M0, M1, M2, M3 hourly readings and zero (see Table 2). The third row of Table 2 contains the Total Consumption (BF) and represents the hourly gross energy consumption, supplied by the PV facility and/or by the public supply grid. The fourth row of Table 2 shows the Self-Consumption (EP), corresponding to the difference between the hourly net production and the NTN, or equivalently, to the part of the total consumption that is not fed from the public supply grid. The fifth row of Table 2 only applies to installation-connected facilities, in which the self-consumed energy does not flow through the public supply grid. Nevertheless, the grid continues to be available and these facilities must contribute to the implied costs in proportion to the Availability Payment (RH) metering point. Finally, the Consumption Metering Point (CMP) and the Production Metering Point (PMP) determine the purchased and sold electricity, the latter being either the hourly net production for group 1 or only the hourly surplus for group 2 [25,26].

Table 2. Defined metering points for net settled facilities. Self-elaboration.

Metering Point	Connection Type	Group	Definition
NFN (Net from Network)	Direct-connected	1 2	$\max\left(\sum_{1\,h}(M3+M0)-\sum_{1\,h}M1,\ 0\right)$
	Installation-connected	1 2	$\max\left(\sum_{1\,h}M3-\sum_{1\,h}M2,\ 0\right)$
NTN (Net to Network)	Direct-connected	1 2	$\max\left(\sum_{1\,h}M1-\sum_{1\,h}(M3+M0),\ 0\right)$
	Installation-connected	1 2	$\max\left(\sum_{1\,h}M2-\sum_{1\,h}M3,\ 0\right)$
BF (Total Consumption)	Direct-connected	1 2	$\sum_{1\,h}(M3+M0)$
	Installation-connected	1 2	$\sum_{1\,h}M3+\sum_{1\,h}M1-\sum_{1\,h}M2$
EP (Self-Consumption)	Direct-connected	1 2	$\sum_{1\,h}(M1)-NTN=BF-NFN$
	Installation-connected	1 2	
RH (Availability Payment)	Direct-connected	1 2	-
	Installation-connected	1 2	$\sum_{1\,h}M1-\sum_{1\,h}M2$
CMP (Consumption Metering Point)	Direct-connected	1	BF
		2	NFN
	Installation-connected	1	BF
		2	NFN
PMP(Production Metering Point)	Direct-connected	1	$\sum_{1\,h}M1$
		2	NTN
	Installation-connected	1	$\sum_{1\,h}M1$
		2	NTN

2.2.2. Billing Concepts

Once the different metering points have been specified, the electricity prices, taxes and the several tariffs for net settled PV facilities can be applied on their basis. Table 3 collects the different billing concepts applied per unit of energy at PV facilities under the Danish net settlement regulatory framework [25,26,29].

The first three columns of Table 3 list the metering points, connection types and groups of PV net settled facilities, and for each one of them the cells corresponding to the billing concepts per unit of energy that are of application have been checked using a green tick icon.

The first of the listed billing elements is the electricity market price (each of the electricity transmission networks in Denmark has its own spot market price: DK1 (West Denmark) and DK2 (East Denmark) [30]). The purchase and sale of electricity at net settled facilities is done under market terms, through an electricity supplier for the consumption and a supplier for the production, which can be the same or different companies [25,26]. The amounts paid to the supplier for the consumption may include a variable part dependent on the purchased electricity and linked to the evolution of the market price plus a fixed monthly subscription. Both the variable and the fixed part conditions depend on the agreement reached with the electricity supplier [31]. For simplicity, Table 3 only shows the spot market price for the energy-dependent part of the supplier tariff applied to the CMP, and neither possible surcharges nor any supplier fixed monthly subscription have been included. Likewise, the same spot market price has been considered as the selling price agreed with the supplier for the production regarding the readings of the PMP. A tariff per unit of energy and/or a monthly fixed subscription may be applied by the supplier for the production in order to cover its costs, which depend on the particular concluded agreement and are not shown at Table 3.

Table 3. Main billing concepts applied on the energy registered at the different metering points of PV net settled facilities. Self-elaboration.

Metering Point	Connection Type	Group	Main Billing Concepts per Unit of Energy [c€/kWh]										
			Market Price	DSO Grid Tariff	Availability Tariff	TSO Grid Tariff	TSO System Tariff	Balance Consumption Tariff	Balance Production Tariff	Feed-in Tariff	PSO Tariff	Reduced PSO Tariff	Electricity Tax
M0+M3	Direct	1		✔									✔
		2		✔									✔
M3	Installation	1		✔									✔
		2		✔									✔
CMP	Direct	1	✔					✔					
		2	✔					✔					
	Installation	1	✔					✔					
		2	✔					✔					
PMP	Direct	1	✔						✔				
		2	✔						✔				
	Installation	1	✔						✔				
		2	✔						✔				
NFN	Direct	1				✔	✔				✔		
		2				✔	✔				✔		
	Installation	1				✔	✔				✔		✔ *
		2				✔	✔				✔		✔ *
NTN	Direct	1								✔			
		2								✔			
	Installation	1								✔			
		2								✔			
EP	Direct	1										✔	
		2										✔	
	Installation	1										✔	
		2										✔	
RH	Direct	1											
		2											
	Installation	1		✔									
		2		✔									

* Only for residential PV facilities up to 6 kW.

The second billing element listed in Table 3 is the distribution system operator (DSO) grid tariff, which is applied on the energy consumed from the network. With this concept, along with DSO fixed subscriptions for the M3/M2 and M1 not shown at Table 3, the DSO covers operation and maintenance costs, losses, depreciations, meter reading and other expenses of the distribution grid [31].

On the other hand, the third billing element in Table 3 is the availability tariff, applied by the DSO on the RH metering point of installation-connected facilities. With this concept, the prosumers pay for the availability of the distribution grid in proportion to their self-consumption. The availability tariff is replaced by a fixed yearly availability subscription for those group 2 installation-connected PV facilities with rated power lower or equal to 50 kW not having the M1 metering point [29].

The fourth and the fifth billing elements shown in Table 3 are the transmission system operator (TSO) grid tariff and the TSO system tariff, which are applied on the NFN metering point. The TSO grid tariff accounts for the operation and maintenance of the transmission grid and its international connections, whereas the TSO system tariff covers the costs of security and quality of the electricity supply [32].

The sixth and the seventh billing elements listed in Table 3 are the balance tariff for consumption and the balance tariff for production. These concepts are applied on the CMP and the PMP, respectively, and are related to the costs for the TSO of the system services and the balance market. The eighth billing element considered in Table 3 is a feed-in tariff paid by the net settled facilities to the TSO for the readings of the NTN metering point [31,32].

The ninth and the tenth billing elements listed in Table 3 are the PSO and the reduced PSO tariffs. The PSO tariff is applied on the NFN metering point of the net settled facilities and is intended mainly to cover the costs incurred by the TSO for subsidizing RE and, to a lesser extent, also for decentralized cogeneration and related research and development activities, among others. This tariff will be phased out by 1 January, 2022 [33]. The reduced PSO tariff excludes the part intended to subsidize RE and is applied on the EP metering point of the PV net settled facilities above 50 kW. Those PV facilities up to 50 kW have whole PSO exemption on the EP metering point readings [23].

The eleventh billing element in Table 3 is the electricity tax, which must be paid to the Danish Treasury for the consumed electricity from the grid. The PV self-consumed fraction of the gross electricity consumption can be exempted from this tax if it is consumed by the producer himself, i.e., within an internal electricity grid. This requirement excludes direct-connected facilities from the electricity tax exemption on the self-consumed electricity, which therefore must pay this tax on their gross consumption [34]. On the other hand, the way in which the exempted PV self-consumed electricity is determined depends on the type of consumer. While the residential PV facilities up to 6 kW retain the hourly net settled basis for the electricity tax (NFN metering point, see Table 3), instantaneous settlement applies for the rest of cases since the entry into force of [35]. Additionally, several electricity tax levels are applied depending on the customer type and the final use of energy, and certain corporate customers can be entitled to either almost full or partial reimbursement of the paid electricity tax [36].

On top of the electricity price, all the billing concepts per unit of energy shown at Table 3 and the several possible fixed monthly subscriptions, a 25% VAT rate is charged in the electricity bill. Private net-settled customers neither deduct the input VAT nor charge VAT on their electricity sales. On the other hand, VAT registered business customers may be entitled to full or partial VAT deduction [37].

From the above analysis and looking at Table 3 it can be concluded that the savings of hourly net settled commercial customers with respect to pure consumption rely mainly on the avoided purchase cost before taxes of the self-consumed energy as well as on the payment of the TSO grid and TSO system tariffs and the PSO tax on the NFN metering point, rather than on the BF metering point. Additionally, in case that these commercial customers are not entitled to full electricity tax and VAT reimbursement, there is an additional saving in the avoided electricity tax and VAT on the self-consumed energy. Likewise, these commercial customers have an additional advantage with the installation-connected type, in paying this tax on M3 rather than on the BF metering point. Residential customers present the same casuistry as the installation-connected commercial customers not entitled to full electricity tax and VAT reimbursement, with the added benefit of hourly rather than instant settled electricity tax.

2.3. Case Study

In order to illustrate the application of the different schemes for hourly net settled PV facilities under the Danish BEK 999/2016 regulatory framework, a case study corresponding to a commercial consumption is undertaken.

The analysis of a commercial consumption profile is less frequent in literature, which increases the value of the presented contribution, and allows dealing with rated powers above the 50 kW regulatory frontier for implementing the direct-connected schemes (see Table 1). Additionally, commercial customers may be entitled to different levels of exemptions on the taxes applied to electricity, which increase the number of the possible comparison outcomes.

The considered PV system is connected to the 0.4 kV low voltage grid, has a rated power of 60 kW (65 kWp), is south oriented and has a fixed optimum slope of 41°, as determined by the solar radiation tool of the Photovoltaic Geographical Information System (PVGIS) [38] for the city of Copenhagen (Denmark). Using the whole PVGIS-SARAH solar data base covering the 2005–2016 period, the global hourly irradiance of an averaged representative day for each month is calculated. Likewise, the output power of the PV system is determined using the PVGIS built-in model, assuming crystalline silicon technology, 14 % of system losses and depending on the irradiance and the temperature of the modules [38].

A different consumption profile has been considered for working and non-working days, based on the data presented at [39]. The joint representation of PV generation and consumption for each month is shown at Figure 2.

In Figure 2, the generation and the consumption corresponding to a particular month have been represented using the same colour, but with different line styles (see Figure 2 caption). It can be seen that the working day consumption (in dotted lines) is maximum and almost flat from 7 am to 13 pm, broadly agreeing with the major PV generation (in solid lines). Then, the consumption is progressively reduced to a base level. However, the non-working day consumption (in dash-dotted lines) is practically constant. Additionally, while the average PV generation at the month of July is 8 times greater than that of December, the highest energy consumption at November only exceeds by near 18% the lowest consumption at the month of July. A small auxiliary consumption for the PV facility has also been taken into account.

Figure 3 represents the DK2 average hourly electricity market price for each month of 2019 [40]. This year has been selected for being the most recent one free of the distortion introduced by the COVID-19 pandemic in the electricity prices. It can be noticed at Figure 3 the characteristic price reduction at the central hours of the day, coincident with the greatest PV generation, as well as the lower electricity prices at the months with higher PV production.

The values assigned to the rest of tariffs and taxes gathered at Table 3, as well as other supplier surcharges and fixed monthly subscriptions, have been listed at Table 4. Representative average values of the supplier tariffs and subscriptions for the type of analysed customer have been employed, as well as the regulated TSO tariffs and governmental taxes for 2019. Likewise, the 2019 tariffs and subscriptions of the DSO operating the grid at the area of Copenhagen have been taken. All the Values in Danish krone (DKK) have been Converted into Euros using the Average Exchange Rate for 2019: 1 DKK= 0.134046 € [41].

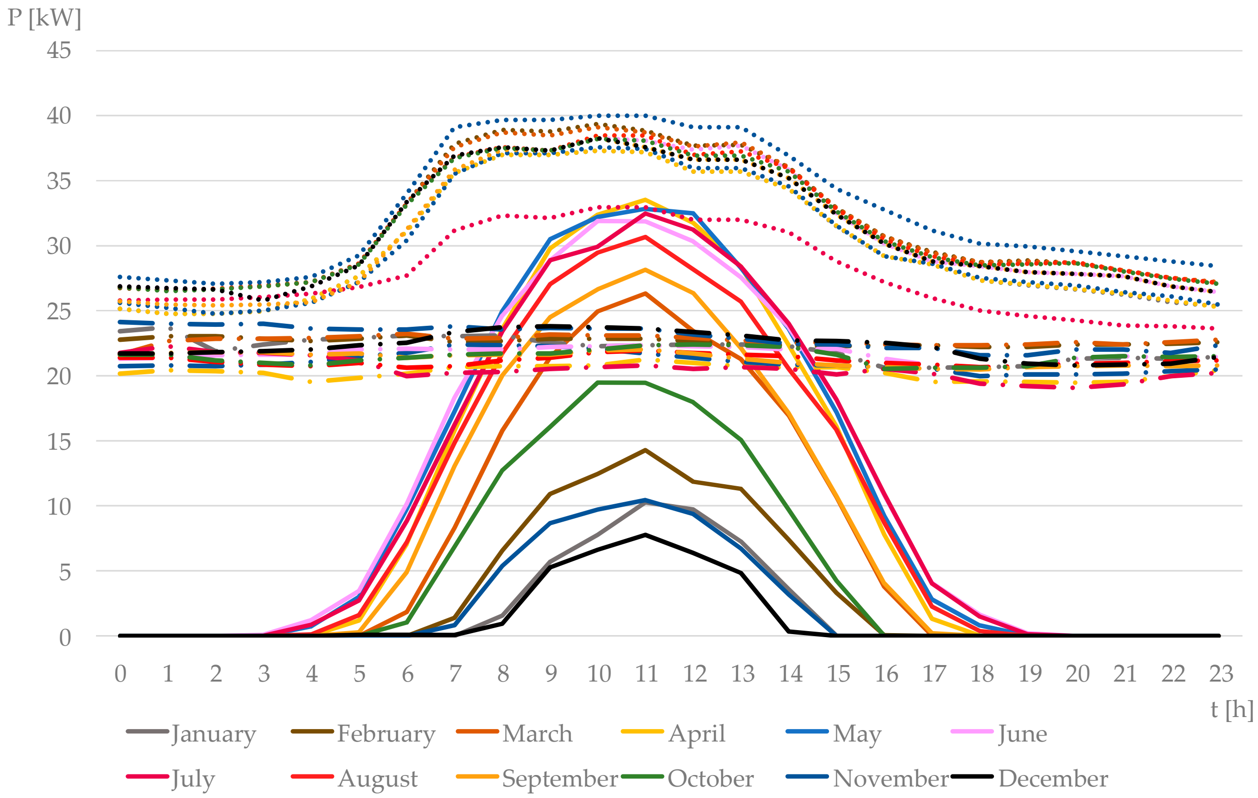

Figure 2. Joint representation of PV generation (solid lines), working day (dotted lines) and non-working day consumption (dash-dotted lines), with different colours for each month. Self-elaboration.

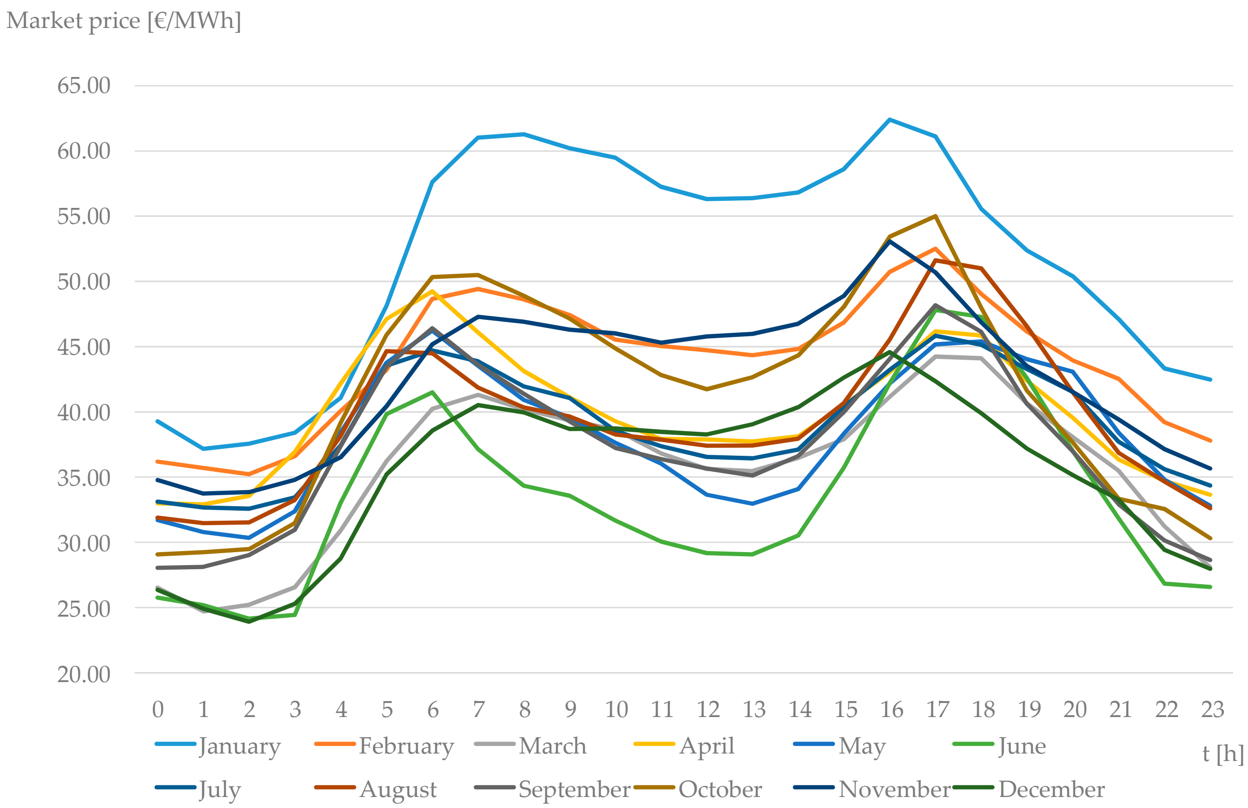

Figure 3. Average hourly price at the Danish DK2 electricity market for each month of 2019. Self-elaboration.

Table 4. Values for the different billing concepts for all the quarters Q1–Q4 in 2019. Self-elaboration.

Tariffs and Taxes [c€/kWh]	Q1	Q2	Q3	Q4
Consumption supplier tariff	1.34	1.34	1.34	1.34
Production supplier tariff	0.13	0.13	0.13	0.13
Low DSO grid tariff (C level)	3.47	3.47	3.38	3.47
Peak* DSO grid tariff (C level)	8.95	-	-	8.95
Availability tariff	3.17	3.17	3.17	3.17
TSO grid tariff	0.59	0.59	0.59	0.59
TSO system tariff	0.48	0.48	0.48	0.48
Balance consumption tariff	0.022	0.022	0.022	0.022
Balance production tariff	0.012	0.012	0.012	0.012
Feed-in tariff	0.04	0.04	0.04	0.04
PSO tax	0.83	0.28	0.00	1.02
Reduced PSO tax	0.00	0.00	0.00	0.300.04
Electricity tax	11.85	11.85	11.85	11.85
Subscriptions [€/month]	**Q1**	**Q2**	**Q3**	**Q4**
Consumption supplier subscription	2.68	2.68	2.68	2.68
DSO subscriptions (for M3/M2 and M1)	6.70	6.70	6.70	6.70
VAT [%]	25.00	25.00	25.00	25.00

* The peak value of the DSO grid tariff applies from 18:00 to 20:00, during the first and the fourth quarters of the year.

3. Results

The performance of the PV facility chosen as a case study has been simulated under the different connection types and groups envisioned in the Danish hourly net settlement regulatory framework BEK 999/2016. Relevant results selected to ease the assessment of the several schemes are now presented.

Figure 4 shows the hourly generation, consumption and energy registered by the metering points M0, M1, M2 and M3 for a plausible representative non-working day of the month of July. The subplot Figure 4a on the left corresponds to a direct-connected arrangement and the subplot Figure 4b on the right to an installation-connected one.

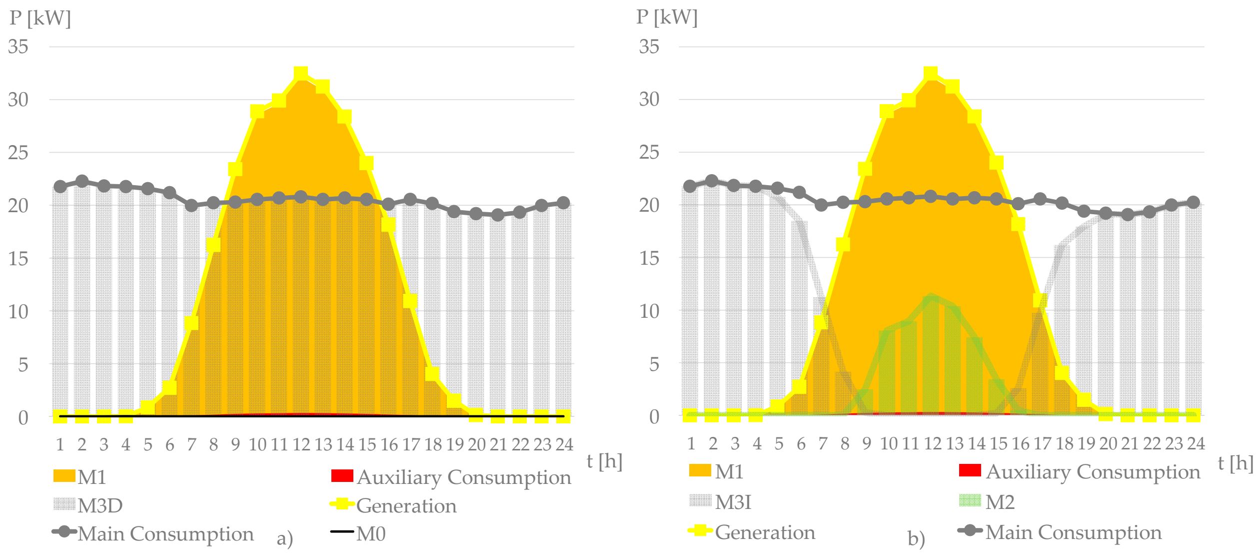

Figure 4. Hourly generation, consumption and energy registered by the M0, M1, M2, M3 metering points for a representative non-working day of July for the case study facility arranged as: (**a**) direct-connected; (**b**) installation-connected. Self-elaboration.

In both subplots it is represented the generated power profile in yellow colour with square markers, the main consumption power profile in grey colour with round markers and a negligible auxiliary consumption in red colour. The area under the generated power profile is shown coloured orange and it corresponds to the net generation metered by M1 along the day. This net generation is fed to the grid in direct-connected facilities, but send to the inner main consumption in installation-connected facilities.

In Figure 4a the reading of M0 is negligible, while the area under the main consumption power profile has been filled using light grey bars. This area represents the energy registered by M3 in a direct-connected arrangement, where all the consumption is supplied by the grid. In Figure 4b the energy registered by M3 has also been represented using light grey bars, but in this case the grid only supplies the consumption that cannot be covered by the own generation. In order to emphasize the different readings and connection points of M3 (see Figure 1), this metering point has been named $M3_D$ in the Figure 4a and $M3_I$ in the Figure 4b captions, respectively. Likewise, the area representing the surplus generated energy metered by M2 has been filled used green bars in the Figure 4b.

As a way of example, the Table 5 shows the values of the energy registered by the several metering points in Table 2, for the time interval 15:00–16:00 in coordinated universal time (UTC).

Table 5. Energy registered by the different metering points during the time interval 15:00–16:00 in coordinated universal time (UTC). Self-elaboration.

Data [kWh]	**Generation: 18.17**	**Main Consumption: 20.10**		**Auxiliary Consumption: 0.05**	
Connection Type		**Direct-Connected**		**Installation-Connected**	
Group		**1**	**2**	**1**	**2**
Metering Point [kWh]					
$\sum_{1\,h} M0$		0.00	0.00	-	-
$\sum_{1\,h} M1$		17.99	17.99	17.99	17.99
$\sum_{1\,h} M2$		-	-	0.48	0.48
$\sum_{1\,h} M3$		20.10	20.10	2.58	2.58
NFN		2.11	2.11	2.11	2.11
NTN		0.00	0.00	0.00	0.00
BF		20.10	20.10	20.10	20.10
EP		17.99	17.99	17.99	17.99
RH		-	-	17.51	17.51
CMP		20.10	2.11	20.10	2.11
PMP		17.99	0.00	17.99	0.00

In the first row of Table 5 it is indicated the total generation and consumption within the analysed time interval. For a given inner distribution of these magnitudes within the considered hour, the physical metering points M0, M1, M2 and M3 instantly register the corresponding energy values, which are hourly accumulated and shown at Table 5. As can be seen, the physical metering points M0, M2 and M3 readings depend on the connection type, but not on the group. The reading of M1 is the only one equal for all the connection types, since the location of this metering point is the same in all cases (see Figure 1).

Using the appropriate expressions of Table 2, the rest of defined metering points are determined for all the connection types and groups and are shown in the rest of rows of Table 5. It can be observed that the metering points NFN, NTN, BF and EP present the same readings for all the connection types and groups, while the CMP and the PMT are depending on the group but not on the connection type.

Once the readings of all the metering points are obtained for the representative day of each month, the monthly cost of electricity is calculated. It is done by applying the values of the different tariffs and taxes in Table 4 on the hourly readings of the several metering points as specified in Table 3, and then adding the corresponding subscriptions and calculating VAT on top. Then, taking a sum of all the monthly costs, the yearly cost is obtained.

Figure 5 represents the yearly cost of electricity during 2019 for all the considered schemes (see the rightmost group of columns), as well as the decomposition of this total cost into the several billing concepts that make it up. The results for direct-connected facilities have been represented in red colour, using dark red for group 1 and light red for group 2. Similarly, green colour has been employed for the results of installation-connected facilities, utilising dark green for group 1 and light green for group 2. For comparison purposes, the results without PV generation for the considered case study have also been represented in black colour. Figure 5 also includes an enlargement scaling up the smaller quantities.

Figure 5. Yearly cost of electricity with decomposition into the several billing concepts. Self-elaboration.

4. Discussion

4.1. Analysis of the Danish BEK 999/2016 Regulatory Framework

The description presented at Section 2 of the Danish BEK 999/2016 regulatory framework for the new hourly net settled PV facilities, with its various connection types, groups, metering points and billing concepts, reveals a significant complexity which hinders the evaluation of the most profitable scheme from an economic perspective. In order to shed light on this issue, the several characteristics of this regulatory framework will be analysed in detail.

Regarding the connection types shown at Figure 1, it can be easily seen that from an electrical point of view they are equivalent, provided that the lines, meters and other electrical losses can be disregarded. Under this assumption, the main difference between the connection types lies on the location of their respective M3 metering points.

The formulation of the energy balances of each of the connection types at Figure 1 allows to establish the equivalence between the readings of their metering points:

$$\mathrm{M1_D} = \mathrm{M1_I}, \tag{1}$$

$$\mathrm{M0_D} = \mathrm{M1_I} + \text{Auxiliary Consumption-Generation}, \tag{2}$$

$$\mathrm{M3_D} = \mathrm{M3_I}\text{-}\mathrm{M2_I} + \text{Generation-Auxiliary Consumption}. \tag{3}$$

where the subscripts $_\mathrm{D}$ and $_\mathrm{I}$ of the several metering points refer to their correspondence to the direct-connected or to the installation-connected types, respectively. The verification of Equations (1)–(3) can be easily checked with the generation and consumption data specified at Table 5 and the readings of the physical metering points M0, M1, M2 and M3 listed there.

The equivalences in (1)–(3) also imply that the readings of the metering points NFN, NTN, BF and EP are also the same for both connection types:

$$\mathrm{NFN_D} = \max\left(\sum_{1\mathrm{h}}(\mathrm{M3_D}+\mathrm{M0_D}) - \sum_{1\mathrm{h}}\mathrm{M1_D},\ 0\right) = \max\left(\sum_{1\mathrm{h}}\mathrm{M3_I} - \sum_{1\mathrm{h}}\mathrm{M2_I},\ 0\right) = \mathrm{NFN_I} \tag{4}$$

$$\mathrm{NTN_D} = \max\left(\sum_{1\mathrm{h}}\mathrm{M1_D} - \sum_{1\mathrm{h}}(\mathrm{M3_D}+\mathrm{M0_D}),\ 0\right) = \max\left(\sum_{1\mathrm{h}}\mathrm{M2_I} - \sum_{1\mathrm{h}}\mathrm{M3_I},\ 0\right) = \mathrm{NTN_I} \tag{5}$$

$$\mathrm{BF_D} = \sum_{1\mathrm{h}}(\mathrm{M3_D}+\mathrm{M0_D}) = \sum_{1\mathrm{h}}\mathrm{M3_I} + \sum_{1\mathrm{h}}\mathrm{M1_I} - \sum_{1\mathrm{h}}\mathrm{M2_I} = \mathrm{BF_I} \tag{6}$$

$$\mathrm{EP_D} = \sum_{1\mathrm{h}}(\mathrm{M1_D}) - \mathrm{NTN_D} = \mathrm{BF_D} - \mathrm{NFN_D} = \sum_{1\mathrm{h}}(\mathrm{M1_I}) - \mathrm{NTN_I} = \mathrm{BF_I} - \mathrm{NFN_I} = \mathrm{EP_I} \tag{7}$$

The identities in (4)–(7) are in any case obvious from a physical point of view. Facilities with the same main and auxiliary consumptions have the same gross consumption BF, regardless of their connection types. Likewise, for the same profile of generation and gross consumption, the self-consumption EP must also be coincident, as also happens with the imports NFN and exports NTN of electricity from/to the grid. The different schemes and their distinct definitions of the numerous metering points may veil, however, this fact. The Equations (4)–(7) can likewise be checked using the values at Table 5. In light of the above explanations, the analysis of the yearly cost of electricity for the several net-settlement schemes illustrated in Figure 5 can be now addressed more easily.

The rightmost group of columns at Figure 5 shows the annual total cost of electricity for the analysed case study, evincing that the cheapest scheme corresponds to installation-connected group 2. Installation-connected group 1 follows with 2.8% of cost increment, and at a significant distance comes direct-connected group 2 with 14.9% and direct-connected group 1 with 17.7% of cost increase, respectively. The reasons for this behaviour must be sought in the varied impact of the several tariffs and taxes on each of the possible net-settlement schemes, which will be now analysed in detail.

4.1.1. Billing Concepts with Different Impact for All the Connection Types and Groups

The second group of columns starting from the right side of Figure 5 shows the annual total cost of electricity excluding the cost of electricity tax and VAT. This would be the cost to be considered in the event that the commercial customer of the case-study is entitled for full electricity tax and VAT reimbursement. In this case, the installation-connected group 2 remains the cheapest scheme, but closely followed by direct-connected group 2 with 0.7% of cost increment, installation-connected group 1 with 3.7% and direct connected group 1 with 4.4% of cost increment. Although the installation-connected group 2 continues to be the cheapest scheme, its difference regarding other variants has been significantly reduced. Whatever possible scenario of partial electricity tax and/or VAT reimbursement would be then comprised between the first and the second rightmost groups of column of Figure 5 (Generally, VAT-registered companies are entitled to electricity tax reimbursement, except for 0.054 c€/kWh. Liberal professions are only entitled to electricity tax reimbursement on consumption for space heating, domestic hot water and comfort cooling, except for 0.054 c€/kWh. From 1 January 2023 on, they will receive however the same treatment as the other VAT-registered companies. In any case, the electricity tax is only deductible in the same proportion as is VAT. Since January 2021, households with electric heating pay a reduced electricity tax of 0.107 c€/kWh for consumption that exceeds 4000 kWh/year [36]). On the other hand, the third and the fourth group of columns starting from the right side of Figure 5 show the annual cost of VAT and of the electricity tax, respectively.

The economic impact of the electricity tax is quite uneven from a general point of view, as it is applied on different metering points depending on the PV facility connection type, customer segment and rated power (see Table 3). If the particular case of residential customers up to 6 kW is excluded, then the charge imposed by the electricity tax is only dependent on the connection type. This can be seen in Figure 5, where direct-connected connection types bear the same electricity tax, which is near 30% higher than that of installation-connected types.

Moreover, the impact of VAT on the total electricity cost is different for all the schemes, since this tax is applied on base amounts that vary with the connection type and group.

Comparing the third and the fourth rightmost group of columns in Figure 5, it can be seen that the cost due to the electricity tax approximately doubles the cost of VAT, and translates to the total cost of electricity its greater value for the direct-connected schemes, in case of not being entitled for electricity tax reimbursement.

4.1.2. Connection-Type Dependent Billing Concepts

A different behaviour is exhibited by the DSO grid tariff and the availability tariff, which correspond to the sixth and the eighth groups of columns starting from the left side of Figure 5. Both billing concepts depend on the grid use, and consequently they only result in an equal economic burden for facilities of the same connection type (see Table 3). As can be observed at Figure 5, the DSO grid tariff imposes a yearly cost for direct-connected types that exceeds in more than 2000 € that of the installation-connected types for the considered case-study. This extra cost is however almost compensated by the cost above 1850 € of the availability tariff, which is exclusively borne by the installation-connected schemes (see the enlargement at Figure 5).

4.1.3. Group Dependent Billing Concepts

In respect of the electricity purchase/selling prices (including eventual supplier surcharges) and the balance consumption/productions tariffs, they are applied on the CMP and the PMP, respectively, and therefore they will affect equally to facilities of the same group (see Tables 2 and 3).

It can also be noted that when valued at the same market price, the net cost of electricity purchases minus sales is equal for all the connection types and groups. Nevertheless, what implies a major cost for group 1 schemes with respect to group 2 ones is mainly the impact of the consumption supplier tariff, and to a lesser extent, also the contribution of the production supplier tariff and the balance consumption and production tariffs.

4.1.4. Billing Concepts with Equal Impact for all the Connection Types and Groups

A direct consequence of the equalities in (4)–(7) is that all the tariffs in Table 3 applied to the involved metering points will result in the same economic burden for all the facilities, regardless of their connection type and group. This will be the case for the TSO grid tariff, the TSO system tariff and the PSO tax applied on the NFN metering point, as well as for the feed-in tariff on the NTN metering point and the reduced PSO tax on the EP metering point.

In this line, it can be seen at the enlargement placed at the top of the Figure 5 the equal cost for all the schemes of the TSO grid and system tariffs, the PSO tax and of the almost negligible reduced PSO tax and the feed-in tariff. The same would apply to all the fixed considered subscriptions, under the assumption that their value is the same for all the schemes.

The Table 6 summarizes the different impact of the several tariffs and taxes on the total electricity cost, organizing them according to their equal effect per connection type and/or group.

Table 6. Classification of the different tariffs and taxes according to their impact on the several schemes. Self-elaboration.

Impact of the Several Tariffs and Taxes on the Total Electricity Cost	
Different for all schemes	Electricity tax, VAT
Connection type dependent	DSO grid tariff, availability tariff, Electricity tax *
Group dependent	Electricity price, (eventually supplier surcharge), balance consumption/production tariffs
Equal for all schemes	TSO grid tariff, TSO system tariff, feed-in tariff, PSO tariff, reduced PSO tariff

* Residential case up to 6 kW excluded.

4.2. The Uneven Impact of Taxes on the Different Customer Segments

As can be seen in the Table 4 and the Figure 5, the electricity tax is the billing concept having by far the greatest impact on the yearly electricity cost. In fact, the electricity tax in 2019 nearly tripled the average wholesale market price of electricity that year [30]. This makes Denmark the European Union (EU) State Member with the most highly taxed electricity for the residential sector [42].

The Figure 6a shows the household electricity price of the second semester of 2019 for the EU countries and other neighbouring states. Denmark ranked first, although followed at short distance by Germany and Belgium. What makes the Danish case singular, however, is its high taxation of electricity, which can be appreciated in Figure 6a as red and blued coloured segments on top of the electricity price before taxes in yellow colour. Thus, the value of the electricity tax is represented in red colour and the value of VAT in blue colour, respectively, maintaining the same colour code for the rest of subplots in Figure 6.

For easing the comparison with other countries the share of these taxes is shown in Figure 6b, where it can be seen that the joint weight of the Danish taxes accounted for more than 64% of its final household electricity price. Specifically, the electricity tax represented above 44% and VAT the remaining 20%. The following country in the ranking was Germany, which globally stood ten percentage points behind Denmark, with a 38% share for electricity tax and 16% for VAT. On the other hand, the EU average share was 25% for electricity tax and 14% for VAT [42].

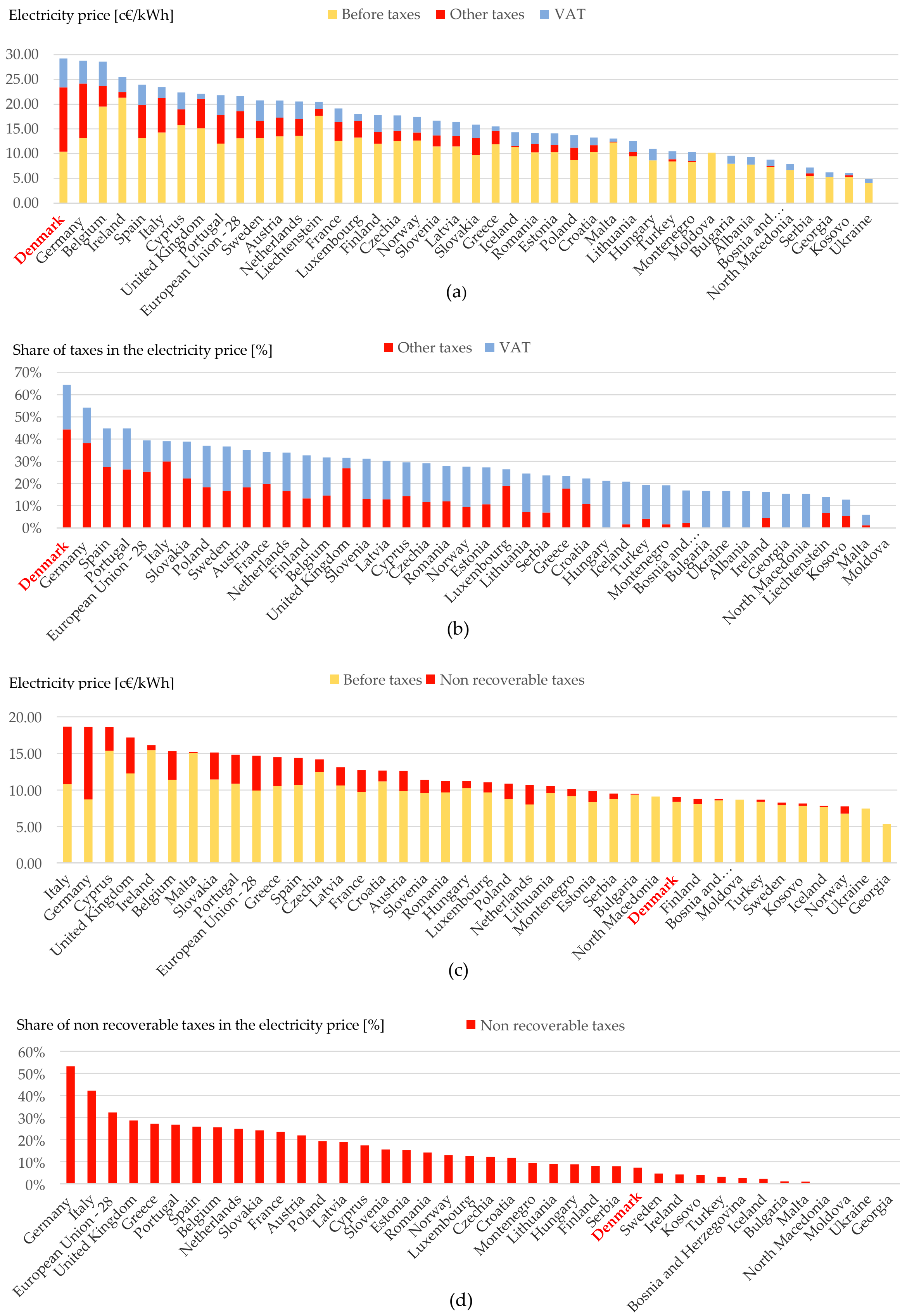

Figure 6. EU and selected neighbouring countries data for 2019 2nd semester: household electricity price (**a**) and its share of taxes (**b**); non-household electricity price (**c**) and share of non-recoverable taxes (**d**). Self-elaboration.

However, the picture changes when the non-household customers entitled for almost full electricity tax and VAT reimbursement are considered. In this sense, Figure 6c represents data for a segment of non-household consumption ranging between 20 MWh and 500 MWh, where the selected case study is comprised. Only the non-recoverable taxes are included in the plot in red colour, added on top of the electricity price before taxes in yellow colour. As can be noticed, Denmark virtually ranked in the last quartile of the represented countries. In fact, its share of non-recoverable taxes was above 7%, well below the 53% of Germany and the average EU 32% (see Figure 6d) [43].

In this way, the Danish average household electricity price before taxes of 10.42 c€/kWh turned into 23.39 c€/kWh after electricity tax and then into 29.24 c€/kWh after VAT, nearly trebling. On the other hand, the more competitive average electricity price before taxes of 8.39 c€/kWh obtained by the non-household studied segment only increased to 9.05 c€/kWh after adding the non-recoverable taxes, i.e., the PSO tax and the small fraction of the electricity tax that is not reimbursed (see Table 4 and footnote 6).

In this vein, the impact of the high electricity tax in Denmark has raised the attention from the Academia. The present fixed tax structure was identified as a factor potentially hampering the adoption of dynamic pricing schemes for the household customers, by hiding the price signal incentive for demand-side flexibility [44]. Likewise, the implementation of several dynamic residential electricity taxation schemes in Demark was investigated in [45], evincing the main trade-offs implied. Thus, the key effect of the high electricity tax on hindering the progress of determined green policies is confirmed in both references.

In another light, the different impact of the electricity tax depending on the customer segment can be regarded as an indirect incentive favouring the adoption of PV self-consumption for the small residential systems and for those commercial customers not entitled to full electricity tax and VAT reimbursement.

According to the data presented in the Figure 6, the avoided electricity cost of the residential self-consumed energy more than triples that of the non-household segment. This point is also confirmed from the case study results presented in the Figure 5, where the yearly cost of electricity in the case of conventional consumption not entitled for electricity tax and VAT reimbursement almost triples that of full reimbursement of taxes (see the black coloured columns of the first and second rightmost groups in Figure 5). Similar conclusions were also presented in [46], where the saved electricity tax, rather than the mere value of the produced energy, is argued to drive the profitability of the residential PV facilities.

A related interesting point is the different impact of the electricity tax and VAT on the profitability of the several net-settlement schemes. As can be appreciated in the Figure 5, it is mainly the electricity tax which causes the different yearly cost outcome for the several net-settlement schemes. An initial rough analysis of the profitability for the full electricity tax and VAT reimbursement case reveals a simple payback time of 29.7 years for the installation-connected group 2 scheme, 30.8 years for the direct-connected group 2, 37.8 years for the installation-connected group 1 and 39.8 years for the direct-connected group 1 scheme, all of them beyond the conservative 25 year lifetime expectancy.

The data for the calculations was obtained from [47], taking the typically higher capital costs of the residential segment (1470 €/kW) and the upper boundary of the operation and maintenance costs (16 €/kW), which could be regarded as a pessimistic scenario in not considering possible cost reductions due to the economies of scale applicable to commercial systems. Any case, when the calculations are repeated assuming non reimbursable electricity tax and VAT, the simple payback time falls to 8.8 years for the installation-connected group 2 scheme, 10.1 for the installation-connected group 1, 24.8 years for direct-connected group 2 and 37.7 for direct-connected group 1.

These results highlight the significantly different indirect incentive degree entailed by the high share of taxes in the final price of electricity in Denmark, depending on the customer segment. This indirect incentive has been recently met with criticism by the Danish Energy Agency for the residential case, viewing it as a kind of socio-economically non efficient type of solar cell expansion. The high support received in the form of tax reimbursements is then contrasted with the near subsidy-free 0.2 c€/kWh average winning surcharge of the 2019 technology-neutral auctions. In this sense, the 6.4 GW of PV projected capacity for 2030 is mainly envisioned for utility scale facilities, with a small 15% share of on-roof PV systems [48].

4.3. Additional Considerations

The rated power of the considered case study facility is eligible for being net settled according to each of the possible connection types and groups, and on this basis the comparison of the economic performance of all the schemes has been conducted.

Nevertheless, it must be taken into account that the ascription to a particular scheme is subject to approval by the Danish Energy Agency, under the Ministry of Climate and Energy. Technical reasons may determine the selection of a particular connection-type. Direct-connected types usually correspond to facilities with greater rated power, connected to higher voltage levels.

Another factor affecting the final economic outcome has to do with the different DSO grid tariffs depending on the voltage level and the point of connection to the grid. Generally, facilities with rated current below 160 A (typically corresponding to a rated power lower than 100 kW) may be connected to the 0.4 kV low voltage grid. This corresponds to a C level DSO grid tariff, as the considered in the analysed case study (see Table 4). Conversely, facilities with greater rated power may be connected to the 0.4 kV side of a 10/0.4 kV transformer station (low B level), or even to higher voltage levels. As the voltage level increases, the DSO grid tariffs are progressively reduced. According to the water fall principle, customers connected to grids with higher voltage levels may avoid paying the costs of the grids with lower voltage levels and transformer stations [49]. Nevertheless, increased DSO fixed subscriptions and additional initial connection costs may apply [50]. There is therefore a varied casuistic that can impact on the final economic outcome of a determined self-consumption scheme, qualifying the general results here presented.

4.4. Future Research

Once the structure of the complex net-settlement schemes for PV self-consumption in Denmark is analysed, and after a basic preliminary profitability calculation, it is clear the need of addressing the optimal design of such systems in order to minimize their lifecycle cost, for both household and non-household customer segments.

Even more, in view of the expected price reductions and the policy goal of emission neutrality the optimization model for the residential customers should include batteries, electric vehicles and heat pumps in order to obtain a comprehensive benchmark for analysing the effect of the different energy policy measures intended to achieve the desired trade-off between loss of revenue for the State and increased electrification levels for permanent decarbonization.

5. Conclusions

The Danish regulatory framework BEK 999/2016 for hourly net settled new PV facilities has been analysed in detail, describing all the envisioned schemes and the different ways in which the several billing concepts are applied.

The advantage of this hourly net settlement arrangement over pure consumption is then identified as relying on the saved cost of the self-consumed energy and the application of the TSO grid and system tariffs as well as the PSO tax on the hourly net from network NFN metering point, rather than on the gross consumption BF metering point. Additionally, customers not entitled to full electricity tax and VAT reimbursement count with the additional advantages of avoiding these taxes on the self-consumed electricity, as well as calculating the electricity tax on a lower energy amount than pure consumers (M3 metering point for installation-connected type commercial customers and NFN for residential customers up to 6 kW).

The existing equivalence relationships between the physical metering points of the different schemes are then stated, which allows identifying which billing concepts have the same impact for all the schemes and which are responsible for their different economic cost.

The obtained conclusions are exemplified on a commercial customer case study, which is less dealt with in the literature and presents a more varied casuistry due to the possibility of full or partial electricity tax and VAT reimbursements. Under the assumption that the same voltage level and grid connection point (and consequently the same DSO grid tariff) can be applied to all the schemes, the cheaper cost corresponds to the installation-connected type group 2.

The billing concept causing the major cost difference between the several schemes is the electricity tax, but its effect is cancelled in case of being entitled to full electricity tax reimbursement. This fact provides an indirect incentive for those producers not entitled for full tax reimbursements for adopting self-consumption, as is the case of residential and liberal professions segments.

The presented analysis of the complex Danish regulatory framework for hourly net settled PV facilities is expected to contribute to discern the different economic outcome that can be expected of the various schemes. Additionally, although particularly complex, this framework presents common traits regarding connection types and certain billing concepts with other regulations, transcending the local value. Although singular in the different taxation level of household and non-household electricity, the analysis of the Danish case can provide valuable insights for other countries with high tax shares. It is expected to ease the comprehension of the leverage points and the policy instruments for modulating the economic results of the facilities and in this way also their path of deployment.

Author Contributions: Conceptualization, H.M., J.d.l.H. and A.A.; methodology, H.M., J.d.l.H. and A.A.; software, H.M. and A.A.; validation, H.M. and J.d.l.H.; formal analysis, H.M., J.d.l.H. and A.A.; investigation, H.M., J.d.l.H. and A.A.; resources, H.M. and A.A.; data curation, H.M., A.A. and S.C.; writing—original draft preparation, H.M.; writing—review and editing, H.M., J.d.l.H. and S.C.; visualization, H.M.; supervision, J.M.; project administration, H.M. and J.d.l.H.; funding acquisition, H.M. and J.d.l.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the research project AGENCIA ESTATAL DE INVESTIGACIÓN RTI2018-100732-B-C22 (MICROEVC).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Acronyms

BF	Total consumption
CMP	Consumption metering point
DKK	Danish krone
DSO	Distribution system operator
EP	Self-consumption
EU	European Union
PMP	Production metering point
PSO	Public service obligation
PV	Solar photovoltaic
NFN	Net from network
NTN	Net to network
RE	Renewable energy
RH	Availability payment
RES-E	Electricity from renewable energy sources
TSO	Transmission system operator

References

1. Ministry of Foreign Affairs. Invest in Denmark. Available online: https://investindk.com/insights/denmark-has-the-worlds-best-energy-system (accessed on 28 February 2021).
2. Danish Ministry of Climate, Energy and Utilities. Denmark's Integrated National Energy and Climate Plan under the Regulation of the European Parliament and of the Council on the Governance of the Energy Union and Climate Action, December 2019. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/dk_final_necp_main_en.pdf (accessed on 28 February 2021).
3. REN21. Renewables 2020 Global Status Report. Paris. 2020. Available online: https://www.ren21.net/gsr-2020/ (accessed on 28 February 2021).
4. IEA. PVPS Annual Report 2019. 2020. Available online: https://iea-pvps.org/wp-content/uploads/2020/05/IEA-PVPS-AR-2019-1.pdf (accessed on 28 February 2021).
5. IRENA. Renewable Energy Statistics 2020. Abu Dhabi, March 2020. Available online: https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020 (accessed on 28 February 2021).
6. EUROPEAN COMMISSION. Clean Energy for All Europeans. COM (2016) 860 Final. Brussels, November 2016. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/com_860_final.pdf (accessed on 28 February 2021).
7. Krönert, F.; Henriksen, G.L.; Boye, S.; Edfeldt, E.; Wiesner, E.; Nilsson, M.F.; Uusitalo, O. Distributed Electricity Production and Self-Consumption in the Nordics. Sweco and Oslo Economics. June 2019. Available online: https://www.nordicenergy.org/article/new-report-distributed-electricity-production-and-self-consumption-in-the-nordics/ (accessed on 28 February 2021).
8. Energistyrelsen. Solcellestatistik for 4. Kvartal 2019. January 2020. Available online: https://www.ft.dk/samling/20191/almdel/KEF/bilag/213/2152522/index.htm (accessed on 28 February 2021).
9. Wang, Z.; Yang, G. Static Operational Impacts of Residential Solar PV Plants on the Medium Voltage Distribution Grids—A Case Study Based on the Danish Island Bornholm. *Energies* **2019**, *12*, 1458. [CrossRef]
10. Stroe, D.I.; Zaharof, A.; Iov, F. Power and Energy Management with Battery Storage for a Hybrid Residential PV-Wind System—A Case Study for Denmark. *Energy Procedia* **2018**, *155*, 464–477. [CrossRef]
11. Gržanić, M.; Capuder, T. The Value of Prosumers' Flexibility under Different Electricity Market Conditions: Case Studies of Denmark and Croatia. In Proceedings of the IEEE PES GTD Grand International Conference and Exposition Asia (GTD Asia), Bangkok, Thailand, 19–23 March 2019; pp. 616–621.
12. Chatzisideris, M.D.; Laurent, A.; Christoforidis, G.C.; Krebs, F.C. Cost-competitiveness of organic photovoltaics for electricity selfconsumption at residential buildings: A comparative study of Denmark and Greece under real market conditions. *Appl. Energy* **2017**, *208*, 471–479. [CrossRef]
13. Chatzisideris, M.D.; Ohm, P.K.; Espinosa, N.; Krebs, F.C.; Laurent, A. Economic and environmental performances of organic photovoltaics with battery storage for residential self-consumption. *Appl. Energy* **2019**, *256*, 113977. [CrossRef]
14. Hou, P.; Douglass, P.J.; Yang, G.; Hielsen, A.H. Optimal scheduling of PV and battery storage at distribution network considering grid tariffs. In Proceedings of the 11th IET International Conference on Advances in Power System Control, Operation and Management (APSCOM 2018), Hong Kong, China, 11–15 November 2018; pp. 1–6.
15. Saviuc, I.; Peremans, H.; Van Passel, S.; Milis, K. Economic Performance of Using Batteries in European Residential Microgrids under the Net-Metering Scheme. *Energies* **2019**, *12*, 165. [CrossRef]
16. Marczinkowski, H.M.; Østergaard, P.A. Residential versus communal combination of photovoltaic and battery in smart energy systems. *Energy* **2018**, *152*, 466–475. [CrossRef]
17. Jäger-Waldau, A.; Bucher, C.; Frederiksen, K.H.B.; Guerro-Lemus, R.; Mason, G.; Mather, B.; Mayr, C.; Moneta, D.; Nikoletatos, J.; Roberts, M.B. Self-consumption of electricity produced from PV systems in apartment buildings—Comparison of the situation in Australia, Austria, Denmark, Germany, Greece, Italy, Spain, Switzerland and the USA. In Proceedings of the 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC), Waikoloa Village, HI, USA, 10–15 June 2018; pp. 1424–1430.
18. Chatzisideris, M.D.; Laurent, A.; Hauschild, M.Z.; Krebs, F.C. Environmental impacts of electricity self-consumption from organic photovoltaic battery systems at industrial facilities in Denmark. *CIRP Ann. Manuf. Technol.* **2017**, *66*, 45–48. [CrossRef]
19. Carli, R.; Dotoli, M.; Jantzen, J.; Kristensen, M.; Othman, S.B. Energy scheduling of a smart microgrid with shared photovoltaic panels and storage: The case of the Ballen marina in Samsø. *Energy* **2020**, *198*, 117188. [CrossRef]
20. Ahamad, N.B.; Othman, M.; Vasquez, J.C.; Guerrero, J.M.; Su, C. Optimal sizing and performance evaluation of a renewable energy based microgrid in future seaport. In Proceedings of the 2018 IEEE International Conference on Industrial Technology (ICIT), Lyon, France, 19–22 February 2018; pp. 1043–1048.
21. De la Hoz, J.; Martín, H.; Alonso, A.; Luna, A.C.; Matas, J.; Vásquez, J.C.; Guerrero, J.M. Regulatory-framework-embedded energy management system for microgrids: The case study of the Spanish self-consumption scheme. *Appl. Energy* **2019**, *251*, 113374. [CrossRef]
22. Alonso, A.; De la Hoz, J.; Martín, H.; Coronas, S.; Salas, P.; Matas, J. A Comprehensive Model for the Design of a Microgrid under Regulatory Constraints Using Synthetical Data Generation and Stochastic Optimization. *Energies* **2020**, *12*, 5590. [CrossRef]
23. Ministry of Climate, Energy and Supply. BEK Nr. 999 of June 29, 2016. Bekendtgørelse om Nettoafregning for Egenproducenter af Elektricitet. Available online: https://www.retsinformation.dk/eli/lta/2016/999 (accessed on 28 February 2021).
24. Ministry of Climate, Energy and Supply. BEK Nr. 1749 of December 26, 2017. Bekendtgørelse om Ændring af Bekendtgørelse om Nettoafregning for Egenproducenter af Elektricitet. Available online: https://www.retsinformation.dk/eli/lta/2017/1749 (accessed on 28 February 2021).

25. Energinet. Retningslinjer for Nettoafregning af Egenproducenter under Engrosmodellen. V 2.1, April 2016. Available online: https://energinet.dk/-/media/Energinet/El-RGD/El-CSI/Dokumenter/Data/Retningslinjer-for-nettoafregning-af-egenproducenter-under-Engrosmodellen-juni-2016.pdf (accessed on 28 February 2021).
26. Energistyrelsen. Vejledning om Beregning af Nettoafregning og opgørelse af Egenproducentens Køb og Salg af Elektricitet på Elmarkedet. December 2018. Available online: https://ens.dk/sites/ens.dk/files/Stoette_vedvarende_energi/energistyrelsens_vejledning_om_beregning_af_nettoafregning_og_opgoerelse_.pdf (accessed on 28 February 2021).
27. Ministry of Climate, Energy and Supply. BEK Nr. 100 of January 29, 2019. Bekendtgørelse om Fritagelse for Betaling til Dækning af Offentlige Forpligtelser i Medfør af § 8 a og § 8 b i Lov om Elforsyning for Øjebliksforbrug af Elektricitet Produceret på Visse Anlæg Ejet af Egenproducenten. Available online: https://www.retsinformation.dk/eli/lta/2019/100 (accessed on 28 February 2021).
28. Energinet. Available online: https://en.energinet.dk/Electricity/Energy-data/System-data (accessed on 28 February 2021).
29. Energinet. *Vejledning—Standard for Nettoafregningsopsætninger i DataHub*; Energinet: Fredericia, Denmark, 2017.
30. Nord Pool, A.S. Available online: https://www.nordpoolgroup.com/Market-data1/Regulating-Power1/Regulating-Prices1/DK-1/Denmark/?view=table (accessed on 28 February 2021).
31. Elpris. Available online: https://elpris.dk/#/article/hvad_bestaar_din_elpris_af (accessed on 28 February 2021).
32. Energinet. Available online: https://energinet.dk/El/Elmarkedet/Tariffer (accessed on 28 February 2021).
33. Energinet. Available online: https://energinet.dk/El/Elmarkedet/Tariffer/PSO (accessed on 28 February 2021).
34. Skattestyrelsen. Available online: https://skat.dk/skat.aspx?oID=2061604&chk=216985&lang=da (accessed on 28 February 2021).
35. Ministry of Climate, Energy and Supply. LOV Nr. 1049 of September 12, 2017. Available online: https://www.retsinformation.dk/eli/lta/2017/1049 (accessed on 28 February 2021).
36. Skattestyrelsen. Available online: https://skat.dk/skat.aspx?oID=2061608&chk=217272 (accessed on 28 February 2021).
37. Skattestyrelsen. Available online: https://skat.dk/skat.aspx?oid=2244622 (accessed on 28 February 2021).
38. Joint Research Center of the European Comission. Photovoltaic Geographical Information System (PVGIS). Available online: https://ec.europa.eu/jrc/en/pvgis (accessed on 28 February 2021).
39. Andersen, F.M.; Henningsen, G.; Møller, N.F.; Larsen, H.V. Long-Term Projections of the Hourly Electricity Consumption in Danish Municipalities. *Energy* **2019**, *186*, 115890. [CrossRef]
40. Noordpool. Available online: https://www.nordpoolgroup.com/historical-market-data/ (accessed on 28 February 2021).
41. European Central Bank. Available online: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-dkk.en.html (accessed on 28 February 2021).
42. Eurostat. Electricity Prices for Household Consumers—Bi-Annual Data. Available online: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_204&lang=en (accessed on 28 February 2021).
43. Eurostat. Electricity prices for Non-Household Consumers—Bi-Annual Data. Available online: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205&lang=en (accessed on 28 February 2021).
44. Katz, J.; Kitzing, L.; Schröder, S.T.; Andersen, F.M.; Morthorst, P.E.; Stryg, M. Household electricity consumers' incentive to choose dynamic pricing under different taxation schemes. *WIREs Energy Environ.* **2018**, *7*, e270. [CrossRef]
45. Albertsen, L.H.; Andersen, M.; Boscán, L.R.; Santos, A.Q. Implementing dynamic electricity taxation in Denmark. *Energy Policy* **2020**, *143*, 111543. [CrossRef]
46. Dansk Energi. Afregning for Individuelle Solcelleanlæg. August 2018. Available online: https://www.danskenergi.dk/sites/danskenergi.dk/files/media/dokumenter/2018-08/Afregning_individuelle_solcelleanlaeg_aug2018.pdf (accessed on 28 February 2021).
47. IRENA. Renewable Power Generation Costs in 2019. Abu Dhabi. 2020. Available online: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf (accessed on 28 February 2021).
48. Energistyrelsen. Analyse af Tidssvarende Udbygning med Solceller under Hensyn til Gældende EU-Regulering. December 2020. Available online: https://ens.dk/sites/ens.dk/files/Sol/analyse_af_tidssvarende_udbygning_med_solceller_under_hensyn_til_gaeldende_eu-regulering_-_december_2020.pdf (accessed on 28 February 2021).
49. Radius Elnet A/S. Metode til Fastlæggelse af Netabonnementer og Nettariffer Pr. 1. April 2016. Available online: https://radiuselnet.dk/wp-content/uploads/El_Metode_til_fastl%C3%A6ggelse_af_netabonnementer_og_nettariffer_1_april_2016.pdf (accessed on 28 February 2021).
50. Radius Elnet A/S. Se Nettariffer, Netabonnement og Tidsopdeling Gældende fra den 1. January 2021. Available online: https://radiuselnet.dk/wp-content/uploads/El_Nettariffer_netabonnement_og_tidsopdeling.pdf (accessed on 28 February 2021).