Is there a Prosumer Pathway? Exploring household solar energy development in Germany, Norway, and the United Kingdom

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Abstract

Prosuming – where private households use photovoltaics to produce electricity at home – has proliferated across Western countries, but growth rates have varied significantly. Focusing on Germany, Norway and the United Kingdom, this article explores the major factors that influence national prosumer figures between 1990 and 2017, and whether a development pathway can be identified. Support schemes, direct regulatory provisions, information and third-party installer markets are analysed through document studies, controlling for domestic context. This study confirms that changes in support schemes have been influential for the development of prosuming in all three countries; access to information and the presence of a third-party market have also been important. There are indications of differences elsewhere in the domestic context. For Germany and the UK, decarbonization has been a significant driving force for policy, unlike in Norway, where a boost in prosuming is now underway. While all three countries show similar early interactions between market and regulatory provisions, different national policy drivers indicate that different national prosumer pathways are possible.

Keywords: *Prosumers; Decentralized Generation; Electricity Policy; Energy Transition*

1 Introduction

Private households are increasingly producing electricity at home, utilizing the opportunities made possible by technical developments in photovoltaics (PV) and other technologies. These *prosumers* – small-scale end-users who, in addition to using electricity from the grid, generate power for their own use and export back into the electricity system – have increased in numbers in many places. Australia, Germany, the UK, Spain, and parts of the USA have seen significant growth in prosuming. Household prosuming – often PV-based – has contributed to changes in business models and electricity markets, including the establishment of new market segments, and has influenced the stock-market values of traditional energy companies [1–3]. Prosumers have established new political interest constellations [3,4] and spurred debate on the need for national capacity-adequacy mechanisms [5]. Some analysts argue that prosuming, in combination with other developments like flexible and intelligent smart grids and electric vehicles, can transform national electricity systems in terms of new physical structures, further enabling the introduction of information technology, as well as institutional and social innovation [6–8].

At the same time prosumer growth rates vary greatly across Western countries. As photovoltaic technology developments and significant price reductions are available across national energy systems, and as factors like solar irradiation do not explain these differences, the main reasons are probably at the domestic level [9]. Moreover, this growth in micro-generation does not always align directly with other renewables policies, for example larger-scale power plants. Few studies have delved into the reasons, holistically investigating the national conditions that influence prosuming figures.

Prosumer developments have varied also in time. Germany implemented its first support programmes in the early 1990s, whereas the UK started some ten years later. Norway, with an electricity sector that is already fully renewable, began supporting prosuming in 2011; thus, a weak trend in prosuming might be expected, but also here the growth curves have been steep. Further, the prosuming curves in Germany, the UK and Norway – at least in the initial stages – show similar exponential shapes. From a rather marginal starting point, prosuming has soared quickly in all three countries, at very different timepoints. This finding is puzzling and warrants further inquiry – especially regarding Norway, which is characterized by low electricity prices and no need for decarbonizing the electricity sector. Here, prosumer numbers are still low, but growth rates are currently high.

This article compares the main policy dynamics that influence household PV prosumer growth in national electricity systems. Focusing on private households using photovoltaics for micro-generation, we analyse the similarities and differences in national prosumer developments over time. We ask: *What are the major factors that influence national prosumer figures, and to what degree can a PV prosumer development pathway with similar interactions between policy and market developments be identified?*

We examine prosumer framework conditions in Germany, the UK and Norway – three countries that vary significantly along several dimensions. Germany and the UK stand as frontrunners and today have many active prosumers, while best practices, policies and regulations for developing prosuming are still being developed and adjusted. Germany initiated a pilot subsidy programme for small-scale PV in 1990, aimed specifically at firstmover households [10]; the UK began a programme to encourage prosuming that included wind and PV in 2002 – more than ten years later. These programmes proved critical for stimulating public interest in and awareness of renewables and in enabling prosuming to emerge. Norway, despite being a frontrunner in electricity-sector liberalization, legally allowed prosuming only from 2010.

To increase the robustness of our findings, we chose similar and different cases, with a special focus on time and technology sensitivity, as the early developments took place when PV technology was significantly less mature. Germany began to develop prosuming roughly ten years before the UK, and twenty years before Norway. Norway shows some signs of going through similar processes as the two other countries, but there are also significant differences. How similar are the processes, and what are the limits to such comparisons? The Norwegian and British electricity sectors de-regulated early, with Germany following at a slower pace. Germany has committed to decarbonize and de-nuclearize its electricity sector; the UK intends to decarbonize partly by increasing the share of nuclear in its electricity mix. Norway is almost fully renewables-based, thanks to its natural endowments. In combination, and following from Mill's joint method of agreement and difference [11], these similarities and differences in background factors make comparisons feasible.

1.2 Comparing prosumer developments

Studies have analysed isolated effects of economic support and other measures on prosuming [1,12–14], and the use of distributed generation in the energy system [15]. However, wider explanations of aggregated micro-decisions in national comparison are rare.

Several studies analyse technical change and optimization, or economic factors, but significantly less attention has been paid to the social aspects, especially at the national or macro-level. However, a growing literature focuses on individuals and household energy choices, including specific decisions related to energy consumption and becoming prosumers, and prosuming uptake through social practice and policy perspectives [16–19]. These studies are often anchored in psychology, behavioural economics, anthropology, sociology or similar disciplines, applying practice theory (or similar) to explain adoption rates, aspects of behaviour, roles, or the scope for change [20,21]. While these studies provide useful micro-foundations for prosumer uptake, they tend to relate to factors like individual values or social practices that are difficult to measure on aggregate levels. Further, they often have limited ambitions regarding generalization.

Little attention has been directed at explaining national prosumer figures, and comparisons across national contexts are difficult to find. However, some studies have addressed prosuming policies. Schleicher-Tappeser [22] argues that prosuming is likely to have a role in changing national energy systems, noting that the speed and ease of this change will depend on regulatory frameworks, business strategies and energy practices. Parag and Sovacool [8] discuss how prosumers could be integrated effectively into electricity markets, underlining that successful integration can be achieved only if markets are differentiated with respect to services, roles and functions. Stakeholders and market actors are found to hold significantly more nuanced approaches than merely representing incumbent 'resistors' to change and new entrants that induce disruptive change [23].

Other studies indicate that approaches to market developments from a 'Varieties of Capitalism' perspective can have important implications for the general uptake of renewables and PV [24]. This may be connected to the observation that in some countries public economic incentives have had an important role in stimulating prosumer developments [1,25], while in other countries household PV uptake has occurred with minimal or no public support [26,27]. PV developments have been shown to be relatively disconnected from natural resource endowments [28], but have been connected to economic support, reduction of transaction costs and bureaucratic hurdles, as well as maturing markets [6]. That late PV adopters may have higher deployment speeds has been linked to experience reducing transaction costs [29].

It is difficult to establish a limited set of determinants for the national integration of PV prosuming by drawing on the general literature and controlling for wider sets of contextual differences. However, some main candidates for explanatory factors stand out. Against the background of the literature mapped above, we examine two sets of explanatory factors for the differences in prosumer numbers. The first is based on the idea that national developments should be compared against the background of *basic national structural conditions and problem characteristics* [30]. These are factors that can facilitate or impede achieving high numbers of prosumers. Such factors are not immune to change and may fluctuate significantly, but they tend to represent relatively stable national conditions over time [31]. They may vary in type and relevance, and include natural resource endowments and institutional structures, energy sources, emission portfolios, and long-term interest constellations in the electricity sector.

The second set of explanations recognizes these conditions and emphasizes how national policy dynamics may lead to different outcomes in prosumer numbers. The dynamic factors – like direct regulations or economic support levels – can be determined politically. While recognizing potential political feedbacks, we approach this by mapping the most prosumer-relevant factors that are the responsibility of politicians and regulators, while controlling for structural and slow-changing characteristics in the countries

Factors may work as barriers to or drivers for prosuming. We operate with three generic categories. The first is *economic incentives* [6], which includes support schemes or tax benefits. These may take various forms, and have been shown to be a potentially crucial factor for prosumer figures [4]. We map relevant economic support over time for each country. Due not least to official policies for increasing PV prosuming returns on investment, such uptake has been found to be high [32], although the implications of differing design elements of support policies show great variance among trends and jurisdictions [4,25]. There has been a focus on EU policy and national regulation for smart grid, including prosuming and PV [33]. Analyses of public benefits in solar subsidies are part of this research strand [34], as is study of how different support designs may have different effects [35].

Our second exploratory factor includes other regulatory requirements and institutional frameworks [6]. These ‘soft costs’ of PV prosuming [36] are often controlled locally. They are typically not economic in nature, but may have a direct or indirect effect on technology diffusion [37]. Examples include building codes and planning regulations, metering requirements, and other energy-market regulations which can have indirect but significant effects on prosumer numbers. Also relevant here is the existence of an ‘official prosumer bureaucracy’ which facilitates prosuming.

Our third generic category is *information practices and the presence of an installer market* [38]. For example, governmental bodies may be mandated to promote prosuming practices – by informing the public about relevant support schemes, providing assistance in dealing with the application and regulatory processes, and spreading general knowledge about prosuming opportunities. While we assume similar access to the global market for technology, there are differences in local access to this technology for potential prosumers.

1.3 Methods and case descriptions

Our comparison of national cases focuses on the limited set of similar factors described above [39, p. 67], relying on data mainly from official sources and research papers. For the German and the UK cases, information is available from official reports, academic literature and official statistics. For Norway, where prosuming is more recent and less information about the effect of regulations is available, an additional three interviews (with a DSO, a public official, and a municipality representative) were conducted between 2015 and 2017, in addition to 58 interviews with prosumers and stakeholders. Interviewees were asked open questions about all the framework factors presented above, including possible barriers, market developments and the effect of incentives.

Germany’s official statistics on installed renewables are categorized by PV system-size, not ownership. A typical residential small-scale PV system is up to 10 kWp [10]; this we use as a proxy for residential PV. In 2014 this segment represented 56% of total German PV capacity – altogether about 850,000 PV systems out of a total of 1.5 million. In that year, installations below 10 kWp represented 5,062 MW, or 13% of total PV capacity [10].

For the UK, the most relevant information on prosumers comes from Feed-in Tariff (FiT) data. These record domestic installations and are used here as a proxy for prosumer figures in the UK. Such installations – typically less than 4 kWp per household – numbered around 750,000 in 2016.

In Norway, 'prosuming' is translated as 'plusskunde' in official policy documents; in Germany and the UK variants of the terms 'micro-generation' 'decentralized energy generation', and 'household PV' are used. Importantly, official statistics do not categorize prosumer figures. As typical PV system size varies amongst these three countries, approximation of the relevant figures was necessary, but our aim here is to analyse general trends in prosumer installation figures: aggregate capacity statistics are not emphasized. These best-estimate figures are the basis upon we make comparisons across the three countries. Norway has no central registry of prosumers. Prosumers are few, and concentrated around urban centres, so we contacted the six largest DSOs (of a total of 136) for information; these data indicated approximately 700 prosumers in Norway by the end of 2016.

2 Prosuming regulations in Germany

Various factors have contributed to Germany's policy decisions to promote renewables. Nuclear energy had a large share of the electricity market in the 1970s, but became increasingly contested, especially after Chernobyl. Coal has always had the largest share of electricity production but is highly polluting. Basic policy instruments to promote renewables were created with the Electricity Feed-In Act of 1991 and the Renewable Energy Act (EEG) in 2000 [40]. A first decision to phase out nuclear energy was made basically in parallel to the EEG. The 2011 Fukushima disaster prompted a strongly reconfirmed nuclear phase-out plan under Angela Merkel [41], with calls for a thorough transformation of the energy system: the *Energiewende*. Initial *Energiewende* plans focused on nuclear phase-out, a significant increase in the share of renewables, and improved energy efficiency. The 2013 revision of national targets aims at a 40–45% renewables share in the electricity system by 2025, and 55–60% by 2035.

Power from PV is one of Germany's three main renewable energy sources, after windpower and biomass. In 2015 coal still accounted for approximately 42% of total gross production of electricity of 647 TWh, but renewables are becoming increasingly important. Renewables now have a share of 29% (as against only 3% in 1990), while nuclear power has dropped to 14% and is to be completely phased out by 2022. The over 1.5 million PV installations in 2014 amounted to 38 GW of installed capacity and contributed to about 6% of Germany's power mix in 2015 [42]. Revisions to the EEG, leading to reductions in support schemes for PV and other renewables, led to a 'massive slump' in annually installed new PV capacity [43] (see Figure 2).

The rise of new non-central energy actors is a striking element in Germany's energy transition, where private households, farmers and citizens' energy cooperatives have invested in renewables [1]. These actors accounted for some 46% of installed PV capacity in 2012 [44]. PV has become the most rapidly growing renewable energy source in the residential sector in Germany.

2.1 Economic support in Germany

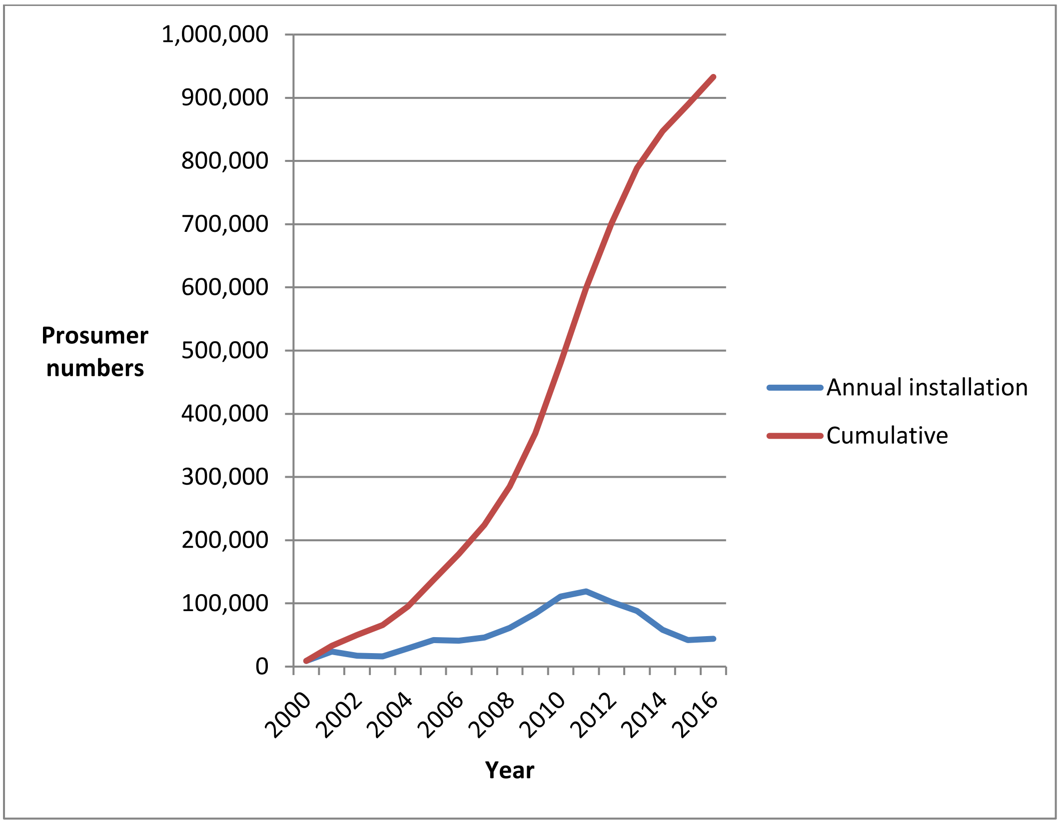
Between 1990 and 1995 Germany established the '1,000 Roofs Programme', an early PV subsidy programme for testing small, decentralized, grid-connected PV systems. Households could get up to 70% of the installation costs of a small PV system (1–5 kWp) reimbursed. These first-movers were expected to submit system-yield data analyses for research purposes. The programme contributed to around 2,000 PV rooftop installations. Despite the high level of support, the private cost per installation still averaged about 10,000 EUR for a 2.6 kWp PV system [45] – primarily attracting pioneer adopters with little expectation of economic gains.

The 1991 Feed-in-Law set the first remuneration for PV electricity feed-in at an average of 8.5ct/kWh. As PV power production costs were about 90 ct/kWh at the time, this first Feed-in Tariff (FIT) also targeted pioneers willing to install PV even at considerable cost. Between 1999 and 2003 the new 100,000 Roofs Programme, which supported the installation of PV systems above 1 kWp, was launched [4]. Offering favourable loan rates, the programme aimed to develop 300 MW of additional PV capacity. Under this programme, 55,000 installations were realized, amounting to 261 MW.

The most fundamental shift to a broader PV market diffusion programme came in 2000, with the adoption of the Renewable Energy Act (EEG). This brought a legal framework with policy instruments aimed at stimulating wider deployment of renewable energy sources. It was amended in 2004, 2009, 2012, 2014 and 2016, always maintaining three central principles: a support scheme for electricity from renewables; a purchase obligation for grid operators;[1] and a solidarity principle for distributing the costs of RES deployment [10].

Figure 1: Number of small-scale (below 10kWp) PV installations 2000-2016 (figure based on [46,47]).

[1] With the EEG amendment of 2014 this has changed for larger renewable electricity plants.



Until the most recent reform of the EEG in 2016, Germany used the FIT scheme with eligibility for PV prosumers, whereby the price for electricity fed into the grid was administratively fixed. The German version guaranteed producers support fixed to the specific RES technology for a period, usually 20 years. In contrast, volume-based support schemes determine quantity targets that may, for instance, be auctioned in a competitive bidding process to determine the price per kWh.

In addition to the price-based support scheme, the EEG included a purchase guarantee and grid priority for renewable electricity. Grid operators were obliged to accept and feed renewable electricity from prosumers into the electricity grid, and to pay fixed prices to PV prosumers. These three principles of EEG offered conditions important for private household investment in PV: investment risks and transactions costs were significantly reduced – the latter particularly important for actors unfamiliar with electricity trading.

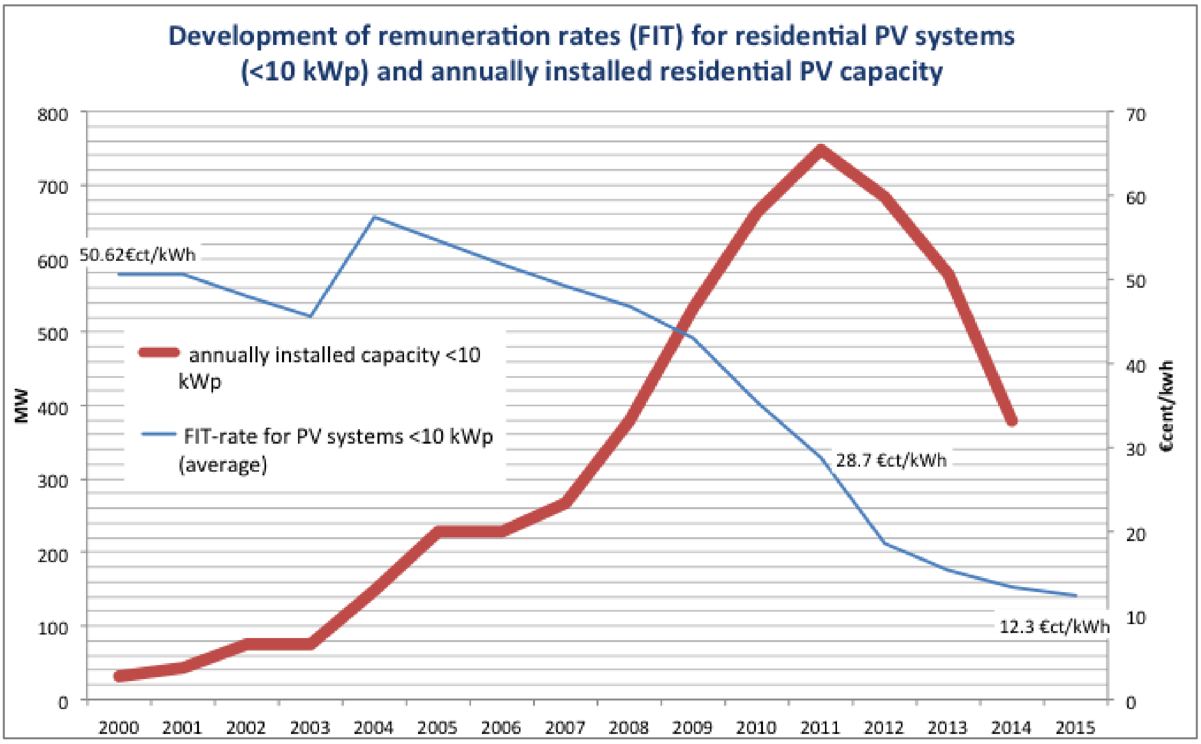
These three pillars of the EEG delivered an effective mix of incentives that boosted the diffusion of PV technology and prosuming (see Figure 1). By increasing investor certainty, sheltered small-scale and new actors' investments, the EEG has fostered small-scale RES - growth for over a decade. Initially, most new capacity involved small-scale PV systems; by 2014 small-scale PV systems accounted for some 20% of newly added capacity. In numbers of annually added installations, systems below 10 kWp still dominated as of 2016 [10].

The high FIT rates are generally regarded as being instrumental for the significant market penetration of prosuming in Germany [14]. Over time, EEG remuneration rates have been lowered, to reflect decreasing system costs for maturing renewable energy technologies.

This has led to changes in the types of installations and in prosumer numbers. In the early phase, high remuneration rates for PV brought a boom in the PV market, in turn leading to concerns about over-subsidization, social fairness and erosion of the solidarity principle. In 2012 the government announced that the FIT for PV would be discontinued when a national cap of 52 GW installed PV capacity was reached [10]. As of 2016, 38 GW PV had been installed.

In 2014 the government introduced additional monthly limitations, to remain in place until the national cap was reached. This arrangement consists of a complex system determining the reduction in FIT levels on a monthly basis in response to the performance of installed capacity – in annual 'corridors'. Should less PV be added than defined in the annual corridor there will be an increase in FIT levels, and vice versa, as per §13 of the 2014 EEG.

Figure 2: Decrease in annually added PV capacity due to degression in remuneration rates



Source: [10].

Especially since 2012, the reduction in remuneration rates has correlated strongly with a significant drop in PV prosuming investment (see Figure 2). However, this drop is not restricted to small residential PV systems, but applies also to larger PV systems. Official FIT rates have been reduced to an extent which cannot be matched by the decreasing PV system prices, bringing economic uncertainty across the German PV market. For residential systems, one study calculated that newly installed small systems can no longer operate economically without a high share of consumption by the producer [46, p.37].

Generation for own use was not intended with the regulator's introduction of the 2000 EEG, which required that all PV electricity be fed into the grid, in order to be eligible for the EEG support scheme. In 2009 self-consumption was allowed; and a related bonus was introduced in the EEG, to stimulate self-consumption so as to prevent grid overload. This bonus even allowed prosumers to receive a reduced FIT rate for the power they consumed at home. However, the bonus had windfall effects, as most prosumers were unable to increase self-consumption levels significantly. With the third EEG reform in 2012 it was phased out.

Despite the removal of the bonus, generation for own consumption had become economically attractive on its own. Grid parity – the point when prosuming delivers electricity at the same cost as the grid – was reached for prosumers around 2012, boosted by increasing electricity retail prices and decreasing FIT rates, and this provided a greater economic rationale for self-consumption [10,13,43].

With the 2014 reform of the EEG, the government introduced an EEG surcharge on self-consumed electricity, albeit lower than the general EEG surcharge. This provision responded to arguments that, since self-consumers satisfy some of their electricity needs with their own power, they contribute less to the grid costs, leaving other consumers with larger bills [14,48]. A study commissioned by the German Energy Ministry concluded that prosuming was not economically feasible without both self-consumption and remuneration, and recommended avoiding a self-consumption surcharge for small PV system operators [46, p. 37]. This has since been followed up for systems under 10 kWp.

By grid parity alone, residential PV systems becomes economically attractive with self-consumption of 25% or more [46]. In general, about 20% self-consumption is now technically possible for small-scale residential PV systems without significant changes in consumption patterns [49]; technical studies indicate that an optimal match of on-site demand can be achieved only with battery systems. Given sufficient storage capacity, the rate of self-consumption can be scaled up to approximately 70%. Other means of increasing self-consumption, such as smart load or smart consumption management, are estimated to increase this rate to about 30% [49], but have costs involved (see [10] for further discussion).

2.2 Other regulatory requirements

The 2000 EEG provisions regarding grid connection, technical requirements, transmission and distribution regulate the relationship and obligations between grid operators and RES producer. Germany's grid operators (involving both the DSO and the TSO) are obliged to connect, purchase, transmit and distribute all RE-based electricity without delay [14]. Changes to the EEG for this was introduced in 2014, but prosumers were exempted from the changes. The connection obligation and the remuneration payment transfer generally apply to the grid operator best suited for connection with the installation, usually a DSO. The upstream TSO is obliged to buy electricity and to pay the DSO according to the defined remuneration rates, and to sell the electricity on the wholesale market. Other requirements, regulating time deadlines and responsibilities, do not seem to represent obstacles to prosuming.

PV installations are further subject to building law, which differs among Germany's state-level jurisdictions. A permit is generally required for roof-based PV installations; permits are normally granted unless the installation disrupts the building or alters visual quality.

Germany is a latecomer to the development of smart grids and accordingly to the rollout of smart meters. Until 2011 there were no smart-meter requirements for small PV installations. With the amendment of the Energy Industry Act (EnWG) in 2011, an obligation for *new* PV installations greater than 7 kWp to install smart meters was introduced.

2.3 Information practices and third-party market

The relatively low bureaucratic complexity in Germany means fewer obstacles for private households to take up prosuming. Transaction costs have been further reduced by access to information and assistance. The many formal institutions throughout the federal system, consumer organizations and associations in the solar sector provide helpful information to potential prosumers. This includes individualized energy-related counselling offered by the national consumer organization and its decentralized member organizations, online guidebooks and interactive calculation tools are available, and there are *solar land maps* produced by municipalities and counties, enabling homeowners to assess the suitability of a roof-mounted PV system. Further, the emergence of third-party PV installation and leasing firms, who assist households in their decision and installation processes, has contributed significantly to reducing the transaction costs involved in becoming prosumers.

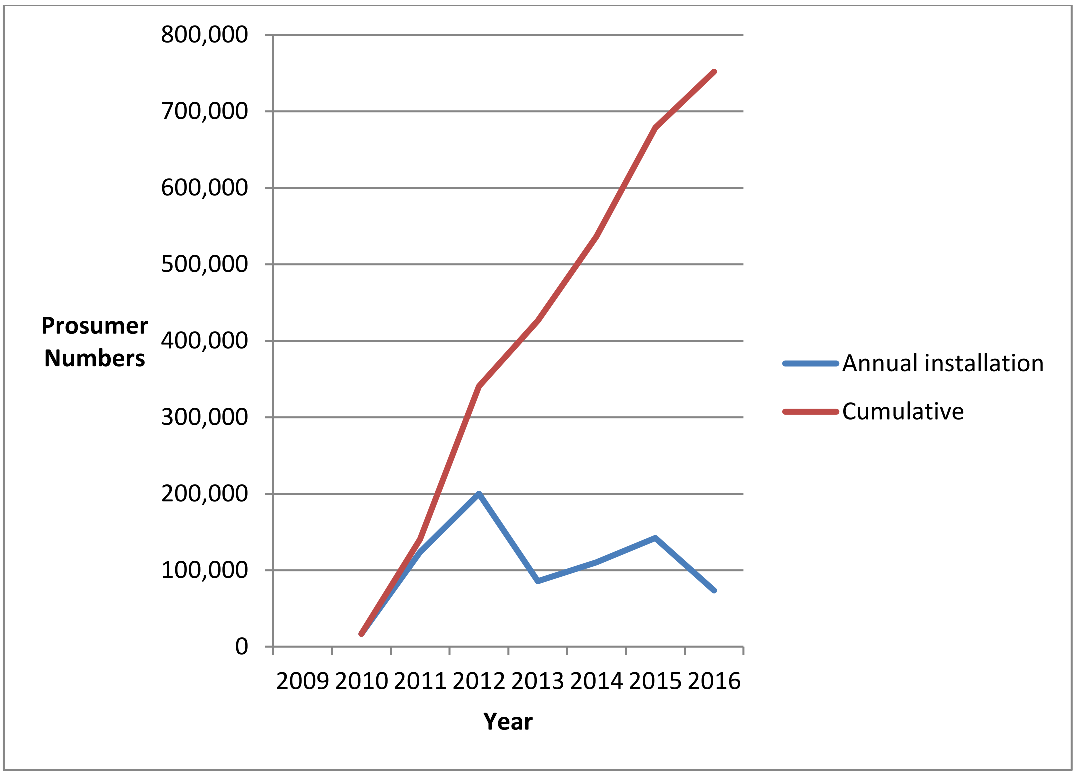
3 Prosumer regulations in the UK

The Electricity Act of 1989 provided for the privatization of the electricity supply industry in the UK, and established a licencing regime that separates generation, distribution and supply activities. A licence is normally required for each of these activities (but not for prosumers). Moreover, licensees are prohibited from carrying out other licensed activities: for example, a generation licensee cannot also hold a transmission, distribution, interconnector or supply licence.

Several pieces of additional recent primary and secondary legislation concern renewable energy production. British prosumers operate in a large-scale and centralized energy system, where electricity generation stood at 339 TWh in 2014 [50]. Since 1970, the fuel mix has moved from heavy reliance on solid fuels to gas, with gas-fired power stations accounting for 33 of the 69 400MW+ power stations in the UK in 2015 [51]. In 2014 the shares of fuels used for electricity generation were as follows: gas 30%, coal 30%, renewables 19%, nuclear 19% and other fuels 2.6% [50]. The number of prosumers has risen sharply from around 2010, according to the FIT registry. Although these figures are not fully representative of all prosumers in the UK (especially prior to FIT) they do indicate the trend.

Figure 3 shows cumulatively installed PV capacity in the UK, 2000–2016. Prior to April 2010, systems were distinguished only by whether they were grid-connected or not. While this makes it difficult to establish exact numbers of domestic installations before that date, the focus here is on the trend, which is quite clear.

Figure 3: Prosuming in the UK (data source: Ofgem FIT statistics).



There are 26.4 million households in the UK, with an average electricity consumption rate of 4,115 kWh and gas consumption rate of 14,263 kWh in 2014 [52]. In 2014, average UK domestic electricity prices, including taxes, were the eighth highest in the IEA, the third highest in the G7, and 17% above the IEA median. By contrast, gas prices, including taxes, were the eleventh lowest in the IEA, the third lowest in the G7, and were 8.2% lower than the IEA median [53].

Until July 2016, energy and climate-change policy in the UK was the responsibility of the Department of Energy and Climate Change (DECC), which was created in 2008. In 2017 the energy and climate portfolio was transferred to the Department of Business, Energy and Industrial Strategy (BEIS). The UK government, however, has no direct control over the electricity and gas markets, which are regulated by the independent Office of Gas and Electricity Markets (Ofgem).

Britain's electricity and energy market is dominated by the 'Big Six': British Gas, EDF, E.ON, npower, Scottish Power and SSE. Together, they supply gas and electricity to over 50 million homes and businesses in the UK. However, since 1997 a few independent suppliers have entered the market, seeking to compete with the Big Six – some with a specifically 'green' profile. The energy market regulator Ofgem has since 2012 made changes aimed at removing barriers for new entrants and improving competition – a total of 48 gas and electricity suppliers by the end of 2016 [54]. Electricity and gas pricing is complex, with considerable differences among the tariffs offered. The public finds the market confusing, which further fuels customer distrust of the 'Big Six' [55].

It has been argued that a 'window of opportunity' for radical change in energy and climate change policy between 2005 and 2013 enabled the UK to be seen, at least for a while, as a world leader in climate-change mitigation [56]. Developments like the publication of the Stern Report in 2007 enabled the shift from an environmental to an economic framing, and the term 'low-carbon economy' gained currency [56]. It is in this context that support for renewable energy technologies and prosuming increased in the UK.

3.1 Economic prosuming support

In 2002 the UK adopted the certificate support scheme Renewable Obligation (RO). This targeted mainly larger installations, and was considered too complicated for prosumers. Repeated calls were made for the Labour government to introduce feed-in tariffs for small-scale generation. This did not occur, but two additional grants-based schemes for prosuming existed at the time: The Major Photovoltaics Demonstration Programme (introduced in 2002) which assisted with PV installations, and the Clear Skies programme (from 2003), which aided other micro-generation installations. Both schemes were replaced in 2006 by the Low Carbon Buildings Programme, also essentially a grant scheme for covering the installation costs of micro-generation technologies in households or not-for-profit sector buildings. However, with no remuneration for the electricity generated, the scheme was not sufficiently attractive to potential prosumers to stimulate significant levels of domestic micro-generation.

Shortly after the creation of the DECC, Secretary of State for Energy and Climate Change Ed Milliband introduced a clause in the 2008 Energy Act to allow for the introduction of a FIT [57]. In 2010, the government launched the FIT Scheme targeting low-carbon installations, including PV, below 5MW. The final design of the FIT was published in February 2010, announcing specific tariffs which were guaranteed for 25 years. Tariffs were set at differing rates depending on installation size, with the best support going to installations of less than 4kWp. This tariff was designed to give an 8% return on investment; the added benefit of index-linking was expected to raise this figure to around 10% [58]. As Figures 4 and 5 show, the FIT had a transformative effect on the uptake of small-scale solar in the UK.

Although none of the support schemes prior to the Feed-in Tariff scheme resulted in significant increase in micro-generation installations, these arrangements served to build the regulatory frameworks and infrastructure underpinning the diffusion of small-scale renewables in the UK. The period 2010–2015 saw an explosive increase in prosumers, predominantly investing in PV systems of up to 4 kWp (see Figure 3).

New domestic PV installations blossomed, peaking in early 2012. The return on investment on domestic PV installations at the time was considerably better than, for example, high-interest individual savings accounts or other readily accessible financial products available to households. This encouraged more households to install PV systems, as prosuming became not only affordable, but also financially attractive as an investment [59].

The initial FIT model combined a high generation tariff with a low export tariff, reflecting the assumption that a design that encouraged on-site use would be the most efficient technically, as well as most likely to 'engender widespread behavioural change' [60,61]. However, the focus of the FIT was diffusion of micro-generation. The initial rate of FIT was high, with a split rate including a 41.3p (€0.52)/kWh generation tariff and 3.1p (€0.04)/kWh export tariff. In view of the future smart-meter rollout, export meters were not fitted. Instead, export was estimated at 50% of generation, and the rate was index-linked and guaranteed for 25 years. Self-consumption did feature in information material, but, in the absence of accurate metering, little attention was paid to this issue.

The FIT presented a good investment opportunity for private households as well as for commercial investors. This led to the growth of a business model of 'free solar' or 'Rent-a-Roof' schemes: domestic solar installations leased by the household. These schemes were developed by companies that installed PV systems on dwellings at no cost to the owner, enabling self-consumption of the electricity generated at no or predetermined cost, while the FIT payments went to the investor. This model created a new kind of self-consumption incentive, as free solar prosumers could benefit financially from the panels mainly as savings on their energy bills through self-consumption.

The unexpectedly rapid uptake of installations in 2010 and 2011 led the DECC to move forward the review of the scheme originally set for 2012 to October 2011 [62]. The consultation argued that factors such as falling costs of PV and rising electricity prices had pushed the returns on investment for PV generators to unsustainable levels. Further, it was argued that this continued trend would, firstly, not provide value for money for electricity consumers who ultimately paid for the FITs through their electricity bills, and, secondly, lead the spending envelope for the scheme to be breached, limiting the availability of FITs for other technologies and later prosumers. A cut on the generation tariff to 21p (€0.27)/kWh effective from December 2011 was scheduled. The cut was delayed until April 2012, following a high-profile court ruling which stated that halving the tariff with only 6 weeks' notice was legally flawed [63]. Further cuts to the generation tariff were made later in 2012, after which time a principle of degression was introduced whereby the FIT would be subject to continued reduction in relation to deployment and installation cost. As of January 2017, the level of the FIT was 4.11p per kWh, as against 41.3p per kWh in the initial FIT [64].

In 2013, the Green Deal, a scheme intended to finance energy-efficiency home improvements, was introduced. This took the form of a loan to be paid back via savings made on energy bills, and consisted of a range of eligible energy-saving measures for homeowners, tenants and businesses – including PV-based prosuming. The intention was that savings on energy bills would outweigh the initial cost over a 25-year period. However, the issue proved more complex, with high transaction costs, and the Green Deal could not offer potential prosumers economic benefits, certainty, or simplicity comparable to what was available under the FIT. In total, only 4,737 arrangements involved micro-generation technology[2] [65] – a figure far short of the expected uptake. In July 2015, the DECC announced that 'in a move to protect taxpayers, there would be no further funding of the Green Deal Finance Company' [66].

3.2 Other regulatory requirements

In addition to the economic support programmes there are other relevant regulations in the UK. The Microgeneration Certification Scheme (MCS) is an industry-led, nationally recognized quality assurance scheme dating back to 2006. It provides third-party certification and gives installers information on matters like planning-permission requirements, metering requirements, notifications to DSOs and various requirements needed for installations to receive the MCS certificate. Further, it provides prosumers with assurance that their installation fulfils certain quality/safety standards, and that calculations of expected yield have been conducted using approved standard assessment procedures. From 2009, FIT eligibility for PV installations required MCS certification.

Bureaucratic procedures for becoming a prosumer were simplified in 2008 by the Permitted Development Rights, which lifted the requirements for planning permission for most domestic micro-generation technologies in the UK. The General Permitted Development Order (GPDO) grants rights to carry out certain limited forms of home development without having to apply for planning permission, with exceptions for some listed buildings and specific conservation areas.

From 1 April 2012, homeowners must provide an Energy Performance Certificate (EPC) with their FIT application, in order to be eligible for the standard FIT rate (a much lower rate is available for homes that do not fulfil these criteria). It is the customer's responsibility to obtain the EPC (in 2017 this cost approximately £45 (€57)) before applying for the FIT. In some cases, this has meant that households have had to make energy improvements to their homes to be eligible for FIT.

3.3 Information practices and third-party market

With the rapid growth in the solar industry, marketing efforts and competition has come a considerable expansion in information available in the UK, from official sources such as Ofgem and DECC, and further non-marketing information from several NGOs. They have provided general information on matters like the costs and returns on investments and how

[2] Figures do not specify how many of these were solar PV

best to utilize technologies to maximize economic and environmental benefits. Some NGOs (e.g. the Energy Saving Trust and the Centre for Alternative Technology) have also offered web-based support tools like PV calculators, enabling potential prosumers to estimate returns on investment.

Advertising has been the main vehicle for spreading information about domestic solar options to prosumers. Ethnographic research on prosumers and installers 2011–2013 found that households received numerous leaflets and quotes from various companies; adverts were placed in local and national newspapers; and there were many new local and national installers [67].

The solar industry became important to the diffusion of prosuming from 2010 onwards. According to the British Photovoltaic Association (BPVA), the number of UK-registered PV installers rose from around 200 in 2009, peaking at 5000 in 2011, before dropping back down again to 1680 in early 2017 (BPVA, personal communication). The UK market leader in commercially owned 'free solar' domestic rooftop installations, A Shade Greener, claims to have installed some 67,000 free PV systems as of 2017.

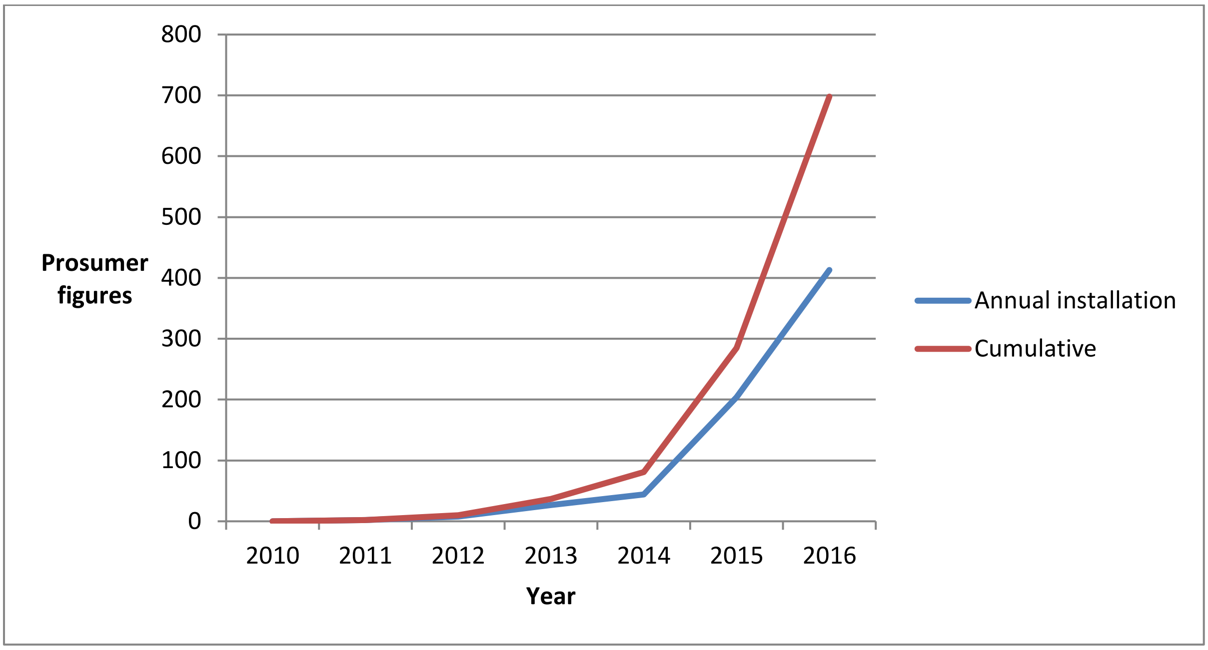
PV installers are regarded as a significant vehicle for the upscaling of prosuming in the UK, where self-installation has been rare. Prosumers usually have little involvement in the technical installation of PV or the administrative and regulatory framework governing grid connection. By contrast, installers tend to be cognizant of matters like EPC requirements, planning and grid connection requirements, and can offer advice, for instance on specific types of solar panels that are acceptable in various areas as well as quotes and FIT rate payback times – but the responsibility for obtaining planning permission under these circumstances remains with the prosumer.

4 Prosumer regulations in Norway

Since 1991, Norway has been an energy frontrunner, liberalizing its electricity market and developing DSO regulation models [68,69]. However, in other areas – like prosuming – Norway is less developed than other European countries. We lack precise figures, but in 2016 there were roughly 700 prosumers nationally, out of approximately 2.5 million end-users and a population of some 5.3 million. Although the trend points upwards, the Norwegian market for PV is very small; by the end of 2015, total installed capacity was about 15 MW, as against 160 MW in Sweden and 790 MW in Denmark [70].

According to an interview with the national regulator NVE, before 2011 there were still no officially registered prosumers in Norway. Hafslund Nett in the Oslo region say they were the first DSO to connect a prosumer in Norway, in 2011 [71]. Interest in prosuming spread, and by the end of 2016 the company had connected 221 prosumers. Other DSOs with significant numbers of prosumers are BKK, Agder Energi Nett, Lyse Energi Nett, Skagerak Energi, and Norgesnett Fredrikstad. These represent the larger companies amongst Norway's 136 grid utilities. The other grid companies in Norway have at most only a few prosumers, according to our NVE interlocutor.

Figure 4: Prosumer figures for the six largest DSOs in Norway, until 2016 (data acquired directly from DSOs)



Electricity generation in Norway is approximately 98% hydropower-based, with annual production of 130–135 TWh depending on annual precipitation levels. The potential is even greater, and there has been a focus on further expanding hydropower as well as windpower – the latter remains poorly developed, despite the high technical potential [72]. Hydropower generation plants are spread across the country in a supplier-centric model. After low investments since the 1990s, the transmission and distribution grids will need major investments over the next years [69,73]. Electricity in Norway has traditionally been cheap compared to general European prices. Denmark and Germany, for example, still charge almost twice Norwegian electricity prices for private consumers; the UK is also significantly more expensive [74].[3] Consumer prices in Norway are transparent and often closely connected to the spot prices set by the Nordic power exchange, Nord Pool. Grid tariffs and taxes are added later, but there are no price safeguards, and free retailer switching is possible [75].

Electricity represents a high share of Norwegian household energy consumption, about 16,000 kWh of a total 20,000 kWh on average [76]. Firewood comes in second, at 3,200 kWh. However, these figures obscure variations related to location, urbanization and type of

[3] Eurostat electricity prices (in 2015 rates), including taxes in € /kWh, are as follow: Norway: 0.166; Denmark 0.304; Germany: 0.297; and UK: 0.201. The cheapest countries are the Balkan states, where prices range from 0.059 to 0.082, and the Eastern European countries, with prices starting around €0.1 /kWh.

dwelling. Smart meters are subject to full national roll-out across Norway by 2019 [77] and will facilitate future prosuming.

As of 2014, a total of 136 District System Operators (DSO) or grid utilities owned and operated local grids, often under municipal ownership. Customer figures range from about 5000 to more than 680,000; 103 of the companies have fewer than 10,000 end-users each: thus, about 75% of the companies deliver electricity to approximately 10% of end-users [78]. The transmission grid is owned and operated by Statnett, the state-owned Transmission System Operator (TSO).

In March 2010, the regulator NVE first allowed prosuming through a general exemption from the regulatory requirements. Under this arrangement, prosumers were loosely defined as customers who generate some electricity and where the 'annual demand for electricity is larger than production, and the household at times generates more than is used' [79]. The exemption was directed at requirements in provisions concerning general regulations on metering, calculation obligations normally compulsory for power producers, and billing of grid services [80]. Now, prosumers were no longer required to register legally as power plants – significantly reducing bureaucratic requirements and transaction costs like balance contracting and certain technical requirements and obligations associated with being legally defined as a 'power plant'. However, this new arrangement provided no formalized prosumer rights; and the grid company retained the right to decide whether to accept the prosumer or not.

The NVE proposed a pricing model, which was adopted by most DSOs with minor variations. Here, self-consumption was free and involved no taxes or other charges. For electricity sent to the grid, the prosumer received payment for the value of the reduced grid loss, in addition to the spot price for the electricity itself. Several DSOs with prosumers have set this rate to about €0.0044 per kWh, with no grid fee – generally regarded as a minor economic benefit.

Under this model, prosumers benefit most from generating for own use. This takes place 'behind the meter', as metering the in- and out-flows between the meter and the grid is all that is required. The main benefits to the prosumer under this model are exemption from having to pay a share of the grid tariff when exporting their electricity; holding a license for electricity generation; metering their production following general metering regulations; and concluding a balance contract with the TSO [81].

According to an interview with an NVE representative, the exemption period was a valuable way of gathering experience under an operating regime. There were public hearings in 2014 with stakeholder inputs; and, after some delays, the regulation entered into force in January 2017.Here, a new legal definition was established: the prosumer is an end-user with production and consumption behind the point of connection to the grid, and where the electricity fed into the grid at no point exceeds 100 kW [82,83]. There was some controversy on this point, as export is metered on an hourly basis, and some DSOs argued that, under certain conditions, an installation might exceed the 100kW maximum. The prosumer will be responsible for not exceeding the limit, and the DSOs for monitoring it.

From January 2017, consumers may opt to become prosumers, and the DSOs are obliged to connect them. It was further decided to continue the simplified input tariff for the electricity exported, as described above. In contrast to the temporary provisions, third parties must now purchase the electricity exported electricity: DSOs may not do so. The prosumer is responsible for complying with the technical requirements of the installation (increasingly arranged through third-party installers), while the DSO is obliged to facilitate the feed-in of electricity as part of its ordinary services.

The tariff structure for prosumers was more specifically defined along the lines of the temporary regime. This mainly concerns exporting, as self-consumption remains free, and importing follows standard tariffs. However, future uncertainties concern possible changes in tariff construction. The roll-out of smart meters with hourly metering by 2019 will enable a shift to more power-based (peak-load) tariffing [84]. This may have advantages for the electricity system but could affect the profitability of prosuming.

4.1 Economic support in Norway

Norway has a limited number of economic support schemes for prosumers, mostly for installation support. A typical private household installation may range from 2 to 10 kWp, with a system price of around NOK 18 (approx. €1.8)/Wp [85]. Some interviewees saw the regulation and tariff structure as 'a kind of incentive', enabling prosumers to use the power they had generated, without the tax that applies to other energy consumption.

The Enova scheme, launched in January 2015, is the only direct national support programme effectively targeting prosumers in Norway [86]. It consists of two elements. First there is support that covers 40% of all investments made in the technical installation, up to a maximum of NOK 10,000 (€1,120). Then an additional installation support of NOK 1,250 (about €140) applies per installed kW, up to 15kW. This support may reach a maximum of NOK 28,750 (about €3000).

Interviewees generally regarded such support as 'a contribution', but insufficient in itself to trigger investments. This is confirmed by a study of prosuming in Rogaland county, in southwestern Norway. For the cheapest technical solution for installing a PV system, Enova support was found to cover only 17.84% of the costs. The great majority (67.7%) of current prosumers in the area did not see the Enova support as the main trigger for their choice of prosuming [87].

In the negotiations for the 2016 State Budget, prosumers were made eligible for Green Certificates. This scheme is a market-based system for supporting renewables investments, as a flexible collaboration between Norway and Sweden. The goal has been to fund and trigger 26.4 TWh of renewables by 2020, shared between the two countries. However, the transaction costs for PV prosuming to access this scheme are too high to be generally relevant in Norway [88].

In addition to national support, three local schemes deserve mention here, as they have attracted prosumer investments. Oslo municipality has perhaps the best-known arrangement, which has been changed from NOK15 per kWh produced, to cover up until 40% of the costs of the technical installation. The campaign will continue until the ceiling of NOK 4 million is reached. According to the project web-page,[4] in November 2015 some 40 homeowners were poised to install PV panels under this arrangement – but the scheme cannot be combined with the Enova programme. Other noteworthy local support schemes are those in Fredrikstad and Hvaler municipalities, both in southeastern Norway. The schemes are similar and are designed to go beyond purely economic support. The idea is to provide competent advice to interested consumers, as well as economic support, and to include certain advanced consumer-steering and inverter-technical elements. Customers wishing to start prosuming under this scheme can choose between packages of 2, 3, and 4 kWp installations, with the 3kWp package being most popular. According to an interviewee from Fredrikstad municipality, when Enova support is included (the two schemes are complementary), this package comes to about €4,240 fully installed, and the calculated back-payment time with stipulated electricity prices is 10.9 years. In Hvaler municipality, prices have been slightly lower, and more than 70 houses received grants by 2015 [89,90].

4.2 Other regulatory requirements

Norway's Plan and Building Act (PBA) is a legal structure that has undergone significant revisions recently. In a very few cases, planning regulations have obstructed household PV installation, when installation was seen to require façade modification. However, practices have been liberalized to allow for façade modifications involving solar panels, and there is little reason to expect this to be a future major barrier. On the other hand, planning and building requirements are managed by local governments. With 422 municipalities in Norway, there may be differences in practices.

The Green Certificates programme are often not deemed particularly important for reducing harmful emissions, as increased renewables generation has been shown *not* to influence emissions to any significant degree in Norway [91]. This is mainly because of the very high share of renewables in Norway's energy mix; the climate-relevant effects of prosuming are limited within the national jurisdiction, and do not provide strong motivation for boosting prosumer numbers.

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[4] http://www.oslosola.no/stotte.html

4.3 Information practices and third-party market

The NVE and Enova are governmental bodies mandated to promote prosuming practices and inform about relevant support schemes, assist in application and regulatory processes, and spread general knowledge about prosuming opportunities. In practice, however, the natural contact-point for support is the DSO, and/or a third-party company that can provide technical solutions and installation.

Little information was available on prosuming until around 2013/2014, when activity started to increase and practices in the larger DSOs became more established. Several interviewees confirmed this, noting the importance of raising awareness of prosuming options, knowledge of accessible economic support, technical solutions, and availability of third-party installer companies. However, these aspects remain somewhat underdeveloped in Norway.

Interviewees indicated varying DSO attitudes to prosuming, although the grid companies play a crucial role in information and facilitation. Other sources of information for potential prosumers are the Sun Energy Association and the NVE, but arguably most important are the growing numbers of installer companies like Solel, Otovo, and Solfangst. In addition, Enova has a role in providing generic support and information. Information availability has improved significantly along with market developments.

After the temporary regulation was adopted in Norway, there were reports of pioneering self-installers. Installation companies are relative newcomers, but new companies and business models are being established, and demand is increasing. One example is Otovo: five days after being established, and without significant marketing efforts, it had received 800 inquiries from potential prosumers [92]. Otovo’s business model is similar to the UK ‘free solar’ scheme, although they are not able to utilize a FIT. Companies like Solel, with more traditional instalment contracts, and Otovo are becoming established in the Norwegian market.

5 National prosumer developments compared

The empirical mapping of the three cases offers some important findings. Firstly, prosumer-figure developments in all three cases – with Norway in an early phase – indicate roughly similar trends, illustrated by the curves in Figures 1, 3 and 4. From a cautious start, the curves in absolute figures show exponential growth in a period. While this is an evident trend in all three countries, the numbers obscure some relevant lessons.

For example, figures on annually installed numbers give a slightly more nuanced picture and help to indicate what kinds of factors vary and influence annual installation rates. For UK in particular the correlation between annual installation numbers and changes in economic support programmes is very clear, and few other factors in the material can explain the changes in installation rates in this period. For Germany there are more factors that may influence the findings on reduced remuneration rates, such as the support for self-consumption in 2009. But also here, the findings show that reduced FIT rates do slow down installation figures.

The background has been roughly similar in all three cases: technological developments. Photovoltaics have seen a radical price reduction globally; and in some countries, support systems are apparently not needed to increase PV installation rates [27]. This does not undermine the hardly surprising finding that generous support schemes boost prosuming, and that changes in support have significant influence on national installation rates.

Also, more structural background such as electricity prices, indirectly influenced by politics prevail. Higher electricity prices will incentivize micro-production, prosuming and self-consumption. Norway has had the lowest electricity prices of the three countries studied here, and analysts have noted this as a factor that may discourage prosuming in Norway as compared to countries with higher electricity prices, such as Germany (highest of the three) and the UK.

There is an important second important structural factor: the stated goal of decarbonizing the electricity sector in all three countries. For both Germany and the UK, the electricity sector remains central to national decarbonization efforts, but not in Norway. Such a structural factor should perhaps not be regarded primarily as a direct driver regarding individual decisions on becoming PV prosumers. Although studies have shown environmental awareness as one of several drivers for prosuming at the individual level [18], this effect appears diffuse. Much of the causal effect of the perceived national need to decarbonize may be political, and, filtered through domestic political processes, may lead to strategies and measures for decarbonizing. In this sense, most of the carbon-reduction driver for prosuming should be expected to translate into the likelihood of a generous support scheme, although there is no guarantee that this would be channelled to micro-production and prosuming. For Germany and the UK, the FITs for this segment were quite generous at one point (for Germany, from the early 2000s to around 2011, for the UK from 2010 to 2015), and then tapered off. For the UK, the reductions were more abrupt than in Germany. Norway, however, has not had a FIT or production-based support scheme.

Also other factors are important. With *other regulatory requirements and institutional frameworks,* our empirical mapping indicates that initially, in all cases, there were some bureaucratic hurdles that were later reduced. These often take the form of requirements or bureaucratic practices for becoming a prosumer, or the need for complex certificates [36]. This is difficult to map for Germany and the UK because of lack of research material on the early stages of the support programmes, the material clearly indicates that the bureaucratic burden of becoming a prosumer is relatively insignifcant today. For Norway we find some initial barriers, like the lack of mainstreaming of façade requirements for PV panels. However, those proved temporary; practices in some municipalities might present difficulties for potential prosumers, but today this does not represent a barrier.

Our findings further indicate complex relationships between some of the factors investigated, not least regarding *information practices* and *the presence of an installer market*. Access to specific, practical information is crucial if prosumer figures are to increase rapidly, and the presence of an installer market contributes significantly to this. However, these companies in all three countries emerge due to increased demand, which again – particularly in the UK case – is linked to fluctuations in FIT rates. This indicates the complexity of the relationship between support schemes, household demand for prosumer services, and access to relevant and practical information about prosuming. The presence of such a market is a strong catalyst for reducing transaction costs, for consumers interesting in prosuming.

Table 1: Summing up comparative explanatory factors

	Germany	UK	Norway
Prosumer developments	Minor increase from 1990, significant increase 2000–2014	Minor increase from 2000, significant increase from 2010	Minor increase from 2011
Background characteristics	Strong need for decarbonization and phasing-out nuclear power	Strong need for decarbonization of electricity production	No need for decarbonization of existing electricity production
Incentives	Direct FIT-based support	Direct FIT-based support, but changing and unstable	Some installation support
Direct regulations and practices	Few bureaucratic hurdles	Few bureaucratic hurdles	Some bureaucratic hurdles, but not significant
Information and presence of a third-party market	Well-developed third-party market for technical installations	Well-developed third-party market for technical installations	Emerging third-party market for technical installations

5.1 Is there a prosumer pathway?

A *prosumer pathway* would be present if uptake in national prosumer figures followed similar development stages, sequenced into reasonably similar phases for the development of a prosumer-figure track and market-policy interactions. Conversely, a finding where new entrants, like Norway, could leap-frog the development stages seen for Germany and the UK would weaken such an explanation.

Similar phases of development of prosuming are observable in all three countries, although the developments are separated by 20 years. Firstly, all three started with technical testing and pilot schemes. In this phase, governmental investment support was the sole economic support. One might expect a 'leaders/laggards' dynamic as seen in environmental policy [93], where later developers could benefit from lessons and technological developments in 'leading' countries. While this is evident for Germany's contribution to developing a PV market, thus contributing to technical developments that favour later developers, we still observe a dynamic where each country goes through similar implementing stages nationally, even in a thirty-year perspective of PV technological development. The UK, and later Norway, had very similar first phases of technological testing within their own contexts, with support programmes for the few.

The next phase has been the reduction of bureaucratic hurdles, or the soft costs [36]. This represents local governmental streamlining of routines and requirements, to reduce the transaction costs of prosuming. Both Germany and the UK did this at an early stage – Norway has done the same since 2011.

The third stage evident in our material involves the establishment of a third-party installer market, supplying practical information to potential prosumers in a way governments are unlikely to be able to. An important function of such a third-party market is to facilitate prosuming investments by reducing informational and practical transaction costs.

A fourth stage could involve the transition to a mass market in which the roles of services, roles and function are separated [8]. Such a mass market could be regarded mature when prosuming gradually becomes independent of subsidies. According to this understanding, none of the three countries studied here show fully mature markets, although examples are emerging in some jurisdictions [27]. Support schemes have been significantly reduced in both Germany and the UK; while this has had visible impact on prosuming uptake, reductions in PV costs may still lead households to install PV panels. This hinges on various factors, including electricity-price developments and grid parity. Especially for Norway, low electricity prices combined with an unclear role for prosuming in the electricity system and the absence of economic support for produced electricity may prove significant obstacles to a fully developed mass market.

The most similar cases are perhaps the German and British ones, not least regarding the need to decarbonize the electricity sector. However, this challenge has been dealt with in quite different ways; apart from high coal dependency, the two differ greatly in their decarbonization approaches, support schemes, political system and general market orientation [24,31]. None of the three countries should therefore be seen as 'very similar', even if the trajectories of prosumer developments are shaped similarly in Germany and the UK. The differences, in combination with the similarities in prosumer outcome (thus far, for Norway), may indicate that important stages of prosumer developments may well hold across jurisdictions and over time. However, the degree to which these stages represent necessary factors for a prosumer pathway requires significant further exploration. Research has shown that, despite similarities in developments, place-specific differences and contextual factors often lead to significant differences in outcomes [94], and that such paths may change [95] direction over time.

6 Conclusions: Prosuming pathways and policy-market interactions

By mapping PV-based household prosuming developments and framework conditions in three countries, this study has explored major factors and how they influence national prosuming developments, and to what degree a PV prosumer pathway can be identified. The three cases show some significant differences – not least as regards diachronic differences in prosumer developments. However, the similarities found for different phases should increase the robustness of the conclusions.

A generous and stable support scheme that addresses grid feed-in emerges as a major factor in promoting prosuming in national electricity systems, as shown in the cases of Germany and the UK. For Norway it is still too early to draw conclusions about support schemes, as prosuming was made available only in 2010, but preliminary evidence indicates that low economic support has acted to limit prosumer figures. However, prosuming has shown a steep and increasing curve, and PV panel price reductions may help to reduce the need for support, although Norway's low electricity prices work in the opposite direction.

Moreover, all three cases indicate that the presence of a third-party installing market is a significant catalyst for mass increase in prosuming. The rise of such a market is not independent of support schemes, although it appears to have a separate effect that boosts prosuming, by delivering expertise, advice, technical solutions and by facilitating the procedures for becoming a prosumer. Also important is the removal of bureaucratic hurdles to prosuming – early in Germany and the UK, and more recently in Norway as well.

In addition to factors that can be directly manipulated politically, background characteristics differ amongst the three countries. Of these, electricity prices influence the attractiveness of prosuming. There are also indications that the political feasibility of facilitating prosuming is heavily influenced by larger contextual structures in the electricity sector, and how they match with prosuming. For Germany and the UK, for example, prosuming fits well with systems in need of decarbonizing, but this is less clear for Norway. However, prosuming has risen in the early phase also there, indicating that prosumer developments do not necessarily have aligned completely with a national driver.

Our material gives some indications as to the phases necessary for the development of prosuming. All three countries started with technical testing and pilot schemes that helped in reducing (local) bureaucratic hurdles, the 'soft costs' [36]. Then came the establishment of a third-party installer market, reducing the transaction costs for potential prosumers. Last, and less certain, is the transition to a mass market where prosumer services like PV-installation companies proliferate, generating practical information and further reducing the transaction costs for potential prosumers.

Many factors remain that may lead to different pathways, such as the enabling role of electricity market trends and new services enabled by trends with smart meters, houses and grids, battery storage, and further reductions in technology costs. These can foster differing developmental trajectories for prosuming and distributed generation in Western electricity systems [95]. Therefore, our findings cannot uncritically be generalized more widely. The background characteristics and political feasibility of prosumer-related policies may create further differences, and policies will have to be calibrated with other needs and challenges for the specific electricity system and the larger choices involved.

However, 'leaders/laggard' dynamics, as discussed in environmental policy [93], where learning produces shortcuts for later developers, are less evident in our material, although learning between Germany and UK may have occurred about the use of FIT support for household prosuming. Although such dynamics may appear, caution is called for in adopting a strong normative stand on prosuming. It may also be that transitions are more geographically and politically situated and local than earlier versions of multi-level perspectives and transitions theories were able to capture [94,96]. Household-based renewable electricity prosuming may fill various roles, such as decarbonizing, de-centralizing, democratizing or modernizing an energy system, as well as encouraging new actor groups that may contribute to significant changes in future electricity systems.

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