Energy Prosumers' Role in the Sustainable Energy System

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Definitions

General definition for the prosumer is based on the words producer and consumer; the term has been coined by Alvin Toffler, who first introduced the producer-consumer, also referred to as a proactive consumer, in his book The Third Wave (Toffler 1981). Toffler refers to prosumers as a group of customers actively taking part in the process of co-creating products. In essence, the prosumer is an agent that produces as least portion of what it consumes. Another commonly used characterization, emphasizing more the customer function of the prosumer, is that of a professional consumer, which refers to an enthusiastic hobbyist or a semi-professional customer that requires close to professional grade products and services, for example, digital cameras, espresso coffee machines, or solar panels. The concept of prosumer has been developed further (e.g., Kotler 1986; Tapscott and Williams 2008), especially in relation to mass customization, marketing, and lately social media. In addition to prosumer, other terms are used to describe the same phenomena, e.g., competent customers (Prahalad and Ramaswamy 2000) or working consumers (Cova and Dalli 2009). Main approaches to general prosumer definition are summarized in Fig. 1.

In the energy sector, prosumers have started to emerge during the past decade with the introduction of affordable renewable energy technologies (RETs), such as solar photo voltaic (PV) panels. A high-level definition of an energy prosumer embraces the multifold nature of the role as a consumer who also produces, sells, trades, or stores energy (Ford et al. 2016). More broadly, the use of smart appliances, communication technologies, electric vehicles (EVs), and battery storage capacities for flexible services is included in the prosumer description (Parag and Sovacool 2016). A consumer even without any energy generation capacity can be called a prosumer. In this case the emphasis is on the proactiveness or the ability to act as a "provider" by offering energy resources, such as electric vehicle (EV) battery, for the energy system demand side flexibility schemes. Energy prosumers are associated mainly with electricity, but also heating, cooling, and transport host a growing number of prosumers.

Energy prosumers are not always called prosumers. European Commission refers to energy prosumers as "active consumers" and defines it as: "a customer or a group of jointly acting customers who consume, store or sell electricity generated on their premises, including through aggregators, or participate in demand response or energy

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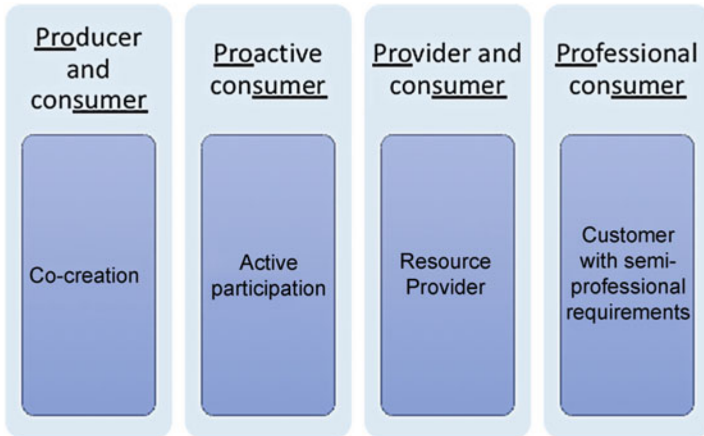


Energy Prosumers' Role in the Sustainable Energy System, Fig. 1 Approaches to define a prosumer (based on Toffler 1981, Kotler 1986, Prahalad and Ramaswamy 2000, Cova and Dalli 2009)

efficiency schemes provided that these activities do not constitute their primary commercial or professional activity" (European Commission 2016).

Furthermore, energy prosumers are sometimes called energy citizens (Bertrand and Primova 2018; Blättel-Mink 2014; Kampman et al. 2016) underlining their role as change agents in the society. The energy citizens are seen as potential agents in supporting energy democracy (Sovacool and Blyth 2015) and sustainability transitions (Geels 2012). Thus, the definition accentuates the participatory aspect of the prosumers as proactive consumers and citizens. Energy citizens relate best to individuals or households, leaving larger prosumers and those of more commercial nature outside this characterization.

Prosumption, in energy, usually refers to the prosumer activities, such as producing energy using solar panels and self-consumption of the energy produced. Ritzer and Jurgenson (2010) suggest that prosumption "involves both production and consumption rather than focusing on either one (production) or the other (consumption)." Prosumerism is used more broadly to cover the social and economic consequences of the prosumers if they gain enough influence. This could be compared to consumerism which is a phenomenon encouraging consumers to acquire products and services in larger and larger quantities (Ritzer and Jurgenson 2010).

Introduction

Sustainability transitions are taking place in multiple sectors. Climate change and ever-growing demand for energy have forced us to think of better and more sustainable ways to produce and consume energy. Main developments that enable the energy transition in the high level are decentralization, digitalization, and electrification (Astarloa et al. 2017). Stimulated by the sharp decrease in costs of distributed energy resources (DERs) such as solar PV and distributed storage, decentralization of the energy system introduces distributed generation (DG) based on the renewable energy sources (RES) in place of centralized, large power plants. The addition of small-scale variable energy sources based on solar and wind requires increased flexibility from the energy system calling for improvements in energy efficiency and demand side management (DSM). Digitalization enables a smart electricity system, the smart grid, that is based on bi-directional flow of energy and information and permits open, real-time, automated operation of the energy system. Digitization, in essence, means transcribing data from an analogue into a digital form using information and communication technology (ICT). Digitalization has a broader systemic meaning and refers to digital transformation of not only technology but also business models and processes (Collin et al. 2015). For example, the energy system is experiencing digitalization in several levels of the system; sensors, Internet of Things (IoT) devices, and smart meters collect data at the consumption (and production) site; the power grid transmits the data; databases and data hubs store the data; data is processed and analyzed; and different applications and services can utilize the data, for instance, for automation and remote control, energy monitoring, or electric vehicle charging management. Electrification is seen critical in achieving long-term carbon goals and concerns large sectors such as transport and heating; for instance, electric mobility is transforming the transportation, and heat pumps are diffusing fast as affordable solutions for heating. Decentralization, digitalization, and electrification together enable big changes in the socio-technical and socioeconomical system, for example, smart cities, smart buildings, and green technology jobs.

The energy system transition is not only technical but involves many levels of changes in technology, infrastructure, business models, and the society. Sustainability transition are often described as socio-technical multilevel transitions (Geels 2012) involving macro-, meso-, and micro-level developments that gradually change established regimes. One of the results of the energy transition is that the energy system, traditionally dominated by large incumbent firms and large power plants, is increasingly opening up to new entrants, one of which is the energy prosumer. The role of energy prosumers is envisioned to be critical for the future sustainable energy system: the prosumers are seen as important additions to decentralized energy system based on RES, and their energy storages are seen as potential future flexibility resources for flexibility and demand response (DR) that are required to manage the increasing variability in the energy generation. European Renewable Energies Federation (EREF) predicts that by 2050, energy citizens in Europe could produce twice as much power as nuclear power stations produce now (Bertrand and Primova 2018). Potential for the prosumers in Europe has also been outlined in the CE Delft report (2016), according to which 83% of households, collectives, micro and small businesses, and public institutions could theoretically become prosumers. In terms of the European households, this would convert to approximately 187 million residential prosumers.

Prosumers are proposed to bring multiple benefits to the energy system, sustainability, and society: reduced carbon emissions, increased use of renewable energy sources, new business opportunities, better access to energy in urban areas, and improved resiliency for developing communities. On the other hand, the prosumerism shakes the existing regimes, and incumbent energy sector stakeholders and increased share of variable energy generation can cause commercial, technical, and operational issues to the electricity system.

Different types of prosumers, their activities and impact on the energy system, and sustainability are discussed in more detail in the following sections. First, prosumers and their role in the energy system are discussed. Second, prosumer challenges posed to the energy system as well as the sustainability aspects of prosumerism are examined. And finally, we summarize the contribution of energy prosumerism to the Sustainable Development Goal (SDG) 7: clean and affordable energy for all.

Energy Prosumers and the Energy System

Prosumer Types

Energy prosumers are not a homogenous group; they come in multiple kinds and sizes. Hence, it is not straightforward to define or categorize prosumers. However, the need for better definition of energy prosumers and their role in the energy system have been called for (e.g., Jacobs 2017). Prosumers have been described in the literature, for example, through their legal status; organizational type; size; type of energy they generate; type of energy sources they use; amount of energy produced, consumed, or sold; or their relationship with the power grid (e.g., European commission 2016; Jacobs 2017; Kampman et al. 2016; Masera and Couture 2015; IEA-RETD 2014; Sajn 2016). At least three approaches can be used to explain the energy prosumers: through their role as energy market participants; based on the energy type they generate and the energy sources they use; and based on their relationship with the power grid (Fig. 2).

Prosumer as a Market Actor

A common way to categorize prosumers is through their role in the energy markets; utilities and retailers consider prosumers as primary customers. Hence, the energy prosumers are commonly grouped into residential, commercial, or industrial. The exact grouping of different prosumers into these categories is not clear-cut, but by applying some simplification, the residential prosumers, also referred to as domestic prosumers, typically include households, apartment buildings, housing associations, cooperatives, or collectives. The residential prosumers normally occupy premises to which electricity is supplied and use the electrical energy for lighting, heating, cooking, and power for domestic and household purposes.

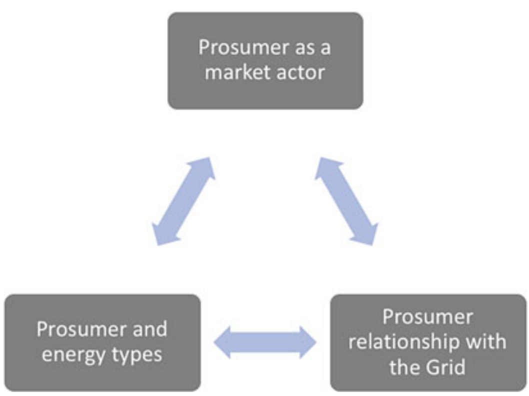
Commercial prosumers contain, e.g., micro, small, or large businesses, department stores, shopping malls, hospitals, schools, offices, or sport facilities. Commercial prosumers use electricity, heating, and cooling for their own use and create products and services for public.

Industrial prosumers are energy consumers engaged in mainly manufacturing and are, for example, factories, mines, mills, plants, or farms. United Nations Industrial Development Organization (Masera and Couture 2015) defines the industrial prosumers as: "industrial operators that produce a portion or all of their on-site power needs with renewable energy technologies (RETs) and sell the excess to the national/local grid or local community."

One of the most straightforward ways to tag prosumers as either residential, commercial, or industrial is based on their energy system size. Although not harmonized even across the European Union (EU) member states, many states categorize prosumers into residential, commercial, and industrial based on the amount of energy they produce and demand. Commonly used limit for residential prosumers is 10 kilowatt (kW), between 10 kW and 250 kW for commercial prosumers, and over 250 kW for industrial prosumers (IEA-RETD 2014).

Besides their size, some sources divide energy prosumers into public and private actors, in which case the smaller public actors are considered residential rather than commercial. Charitable institutions or places of worship are often considered to be residential in nature (Sajn 2016). Likewise, depending on the source and their production size, agricultural farmers are considered either residential, commercial, or industrial.

Another aspect to energy prosumer types is the prosumer groups. By definition (European Commission 2016), the prosumers can organize into groups and communities, which blurs the abovementioned attempt of categorization to an extent as sometimes the prosumers groups are also called prosumers. Organizing into groups potentially enhance the prosumers' bargaining position in the energy markets as they can combine resources and trade large amounts of energy. Prosumers within close proximity from each other belong to the same subsection of the electricity system, a micro-grid. These prosumer micro-grids may act as single entities in the electricity market, and the participating prosumers may generate, store, and sell energy within their micro-grid community. An example of such micro-grid is a residential block or a housing community. Besides close proximity energy communities, the energy prosumers may also form virtual communities, for example, virtual power plants (VPPs) (Rathnayaka et al. 2014). VPPs have existed well before the



Energy Prosumers' Role in the Sustainable Energy System, Fig. 2 Different characteristics of the energy prosumer

prosumer era, but their importance to the electricity system is growing. Yet another example of virtual prosumer community is peer-to-peer (P2P) trading of energy. In this scenario, prosumers produce energy and sell excess energy to any interested party using a trading platform based, for example, on blockchain technology (Parag and Sovacool 2016).

Rules of engagement in the energy markets differ for different customer categories. Residential prosumers, for example, experience higher energy retail price levels than commercial and industrial prosumers that can purchase energy from wholesale markets or auctions that have minimum purchase limits for participants. Industrial-scale prosumers have access to lower retail energy rates than smaller consumer and prosumers. This is one of the reasons why industrial self-generation systems have struggled to become commercially viable due to low retail energy rates. Electricity rate structures also vary for different types of customers. For example, commercial and industrial customers include in many countries both volumetric and demand component residential customers pay for volumetric component and a fixed rate. Furthermore, different countries apply different tax structures for different customer types in the form of income, value-added (VAT), sales, energy, and carbon taxes. Some countries allow VAT deductions from investments made by commercial prosumers to solar PV, for example, in Finland, businesses are able to deduct 25% of their investment in solar PV systems (BusinessFinland 2018). In the USA, the PV system investments by commercial customers can be depreciated with accelerated schedule (IEA-RETD 2014).

Due to their multifaceted and somewhat unclear role, concerns over the legal status of energy prosumers has been raised (Cseres 2018; Jacobs 2017). For example, while EU considers prosumers as active consumers, it does not define precisely who falls within the concept yet leaving the rights and obligations of prosumers underdefined. As a result, the absence of clear legal status raises questions, and the practices to manage prosumers vary between the EU member states.

Prosumer and Energy Types

Prosumer literature mostly focuses on electricity, but microgeneration of heat and cooling also fits with the energy prosumer meaning.

Electricity. Prosumers generate electricity mostly from renewable energy sources (RES); most popular energy sources for micro- and small-scale energy production are solar and wind. With declining cost for the small-scale solar PV systems combined with attractive economic policy incentives offered by governments, many markets have experienced rapid growth in their prosumer base. For example, there are well over million prosumers in Germany, and according to some projections, the prosumer base could be as high as ten million by 2030 (Flaute et al. 2017). On-site electricity can also be generated using small-scale wind turbines or geothermal or hydropower pumps or from biomass using solid wastes or biogas. Especially agricultural farms are in a good position to utilize biomass-based power generation.

Heating can be locally generated using geothermal (or air) heat pumps, solar thermal collectors, or biomass processors. Industrial prosumers may rely on nonrenewable energy sources such as using gas or diesel motors. Besides producing heat locally, prosumers have been studied in the context of district heating (DH) systems (Brange et al. 2016). Like, electricity systems, DH systems have traditionally been centralized large-scale fossil fuel-based production units. DH systems are envisioned to play an important role in the future sustainable energy systems. As part of the sustainability transition, also the DH systems are becoming more resource efficient and decentralized and are relying more on RES, enabling the energy prosumers to participate in the DH generation. While electricity is dominating the heating globally, DH systems provide about 50% of heating especially in the Northern countries (Werner 2017). Furthermore, combined heat-and-power (CHP) generation has potential especially for agricultural and industrial prosumers.

Cooling, similar to heating, is most commonly based on electricity, i.e., the prosumption of cooling is often considered derived from solar PV or heat pumps. Solar thermal collectors are however another way to produce cooling locally (ESTIF 2018). Prosumption of cooling is more common among larger commercial and industrial prosumers. District cooling (DC) systems are not as common as DH systems, but do exist in large cities in Europe and in large cities in the Southern Hemisphere (Werner 2017).

Prosumers' Relationship with the Grid

Yet another approach to describe energy prosumers is based on their relationship with the electricity grid or comparably with the district heating system: the energy prosumers can either be connected to the grid or remain off-grid.

Off-grid prosumers have two main drivers to remain independent from the grid: lack of access to the electricity grid and desire to produce enough energy to fulfill their demand. Off-grid prosumers are more common in rural areas or developing countries or where electricity price is considerably higher than the cost of self-generation. The rural off-grid prosumers are often agricultural entrepreneurs in remote communities taking care of their electricity, heating, and cooling needs (Masera and Couture 2015). Energy storage is important part of the off-grid prosumption as it helps balancing the energy generation and consumption times and hence contributes to higher self-consumption rate.

A societal concern of more and more prosumers leaving the grid is the resulting increase of retail electricity rates for those that remain connected due to the network rate component of the grid being distributed between fewer ratepayers. This in turn makes leaving the grid attractive also for those who originally stayed, potentially escalating a utility death spiral taking place (Severance 2011).

Majority of the prosumers produce only part of the energy they demand and stay connected to the grid. Grid-connected prosumers rely on the electricity from the grid to varying degrees. Self-consumption can be a way to gain savings in electricity bill, especially if electricity rates are high. On the other hand, attractive tariff plans, such as feed-in tariffs (FITs) and net metering, have encouraged prosumers to feed all, or substantial amount of, energy to the grid in some markets to an extent that it has become an economic challenge for the utilities. Commercial prosumers generally have higher self-consumption rates than residential prosumers. For example, commercial and manufacturing buildings in Germany and Spain can achieve self-use ratios of 75–100% (IEA-RETD 2014). Grid-connected prosumers have a broad set of opportunities to be active in the energy markets. They can, for example, participate in flexibility and demand response schemes orchestrated by energy companies, aggregators for energy service companies (ESCO). Grid-connected prosumers can also trade energy in virtual communities and be members of VPPs or micro-grid communities.

Prosumer Activities in the Energy System

There are various approaches to describe prosumer participation in the energy system. Technology-focused approach associates prosumers with electric vehicles (EVs), energy storage, renewable energy technologies (RETs), automation and remote management, or smart buildings. A social approach emphasizes the prosumer roles in energy communities in which they share or trade energy and hence increase the significance of DER. Ecosystem approach considers prosumers as co-creators of value and innovations through offering feedback, lead-testing products, and participating in co-development.

Perhaps the most used approach to describe a prosumer activity is through their on-site energy generation, be it electricity, heating, or cooling. If enough consumers convert into prosumers, they can become a relevant and influential part of DG. Most popular way for prosumer energy generation is the use of solar photovoltaic panels. IEA estimates that global renewable energy capacity will increase by 43% resulting as expansion of over 920 GW between 2017 and 2022 and that solar PV capacity reaches 740 GW by 2022 (IEA 2017a). If the growing trend of installations continues, it has huge impact on the power system in all levels and also on the electricity market. Diffusion of solar PV varies by country and still depends on policy incentives, taxation, and legislative environment. Germany has incentivized solar PV investments, and the prosumer takeoff has been fast (e.g., Flaute et al. 2017). The commercialization of other types of microgeneration like micro wind turbines or micro turbines using combustible fuel has been minor compared to solar PVs.

Energy prosumers can organize in communities and sell excess energy they produce. Energy selling can take place with the main power grid or in micro-grids, virtual communities, or peer-to-peer (P2P). Feeding excess energy back to the power grid is enabled in most markets and incentivized in some (Ramirez et al. 2017). Even though there is a lot of excitement regarding the potential of P2P energy sales, technology platforms and business model readiness are currently in demonstration phase, and regulatory and legislative environment will require adjustments (Martin 2015). Technology enablers such as blockchain have recently gained attention, and pilot projects are being rolled out in different parts of the world. The real applicability of the P2P models remains open, partially due to regulative environment currently in place in the energy sector. However, once the prosumers start to organize in communities, their bargaining power in the energy markets will grow substantially.

Current energy prosumer research focuses heavily on analyzing consumers and prosumers as participants in demand response (DR). Utilities are focusing on extending the DR from industrial customers to households as a way to direct electricity consumption away from peak hour, thus reducing the risk of congestion and the needs for network infrastructure investments. In this scenario, prosumers could be home battery owners or EV owners with a vehicle-to-grid (V2G) connection that allows them to offer their batteries for balancing loads during peak hours. Majority of research related to household demand response focuses on the technical management of DR, e.g., load shifting techniques and algorithms (e.g., Haider et al. 2016). Consumer willingness to participate in demand response has been studied, e.g., Molderink et al. (2010). Consumers can be willing to participate, but they expect relatively high incentives to change their energy consumption behavior or to allow automated control of their electricity. Time-of-use (TOU) price mechanisms are a way to introduce dynamic pricing that shifts energy use during off-peak hours and also encourages DR participation.

Importance of distributed energy storage is one of the rising topics in prosumer research; the potential to cost-efficiently store energy will increase the relevance of DG and prosumer from the power grid perspective as they can become significant flexibility resources to the grid. EV users can connect their batteries to the electrical energy system in three ways: using smart charging, EV battery as a domestic backup power (vehicle-to-home (V2H)), and EV energy storage as a power resource for the public power system (vehicle-to-grid (V2G)). With growing tendency to electrify societies, EV sales are increasing globally (IEA 2017b).

A less researched potential for prosumers to become active participants in the energy ecosystem is through open innovation or value co-creation. Co-creation is based on open innovation principles according to which companies collaborate with external stakeholders to innovate new products and services (Prahalad and Ramaswamy 2004; Chesbrough and Appleyard 2007). Consumers can, for example, take place in crowdsourcing campaigns or volunteer as lead users to test new products and services. Living labs and smart cities are often cited as milieus for co-creation in the energy space.

Enablers and Drivers for Energy Prosumerism

Correct mix of economic and noneconomic factors needs to be in place for consumers to adopt new technologies (Rickerson et al. 2014). National conditions such as available rooftop space in cities influence the prosumer potential. Estimating the roof space is essential for understanding solar PV potential especially in densely populated cities, for example, in Southeast Asia (Byrne et al. 2015). Solar radiation, or insolation, varies in different geographic areas having an effect on the maximum potential of solar energy generation. The Nordic countries, for example, experience far less insolation than the countries closer to the equator.

Availability of technology enablers is a basic requirement for energy prosumption. Solar PV has become efficient and affordable. Home battery storage solutions are developing, and price levels are starting to decrease. Electricity grids are being upgraded into smart grids that enable bidirectional flow of energy and information generating a large amount of consumption, production, and distribution data. Smart meters which are part of an automatic measurement infrastructure (AMI) manage energy measurement and control and provide vast amounts of production and consumption data which in turn can be used to provide better tools for energy monitoring, automation of prosumer management, remote control applications, and value-added services, all of which can lower the threshold for consumer to prosumer evolution. Smart meters are being rolled out in different European countries (Zhou and Brown 2017) with varying speed and timing. Home energy management systems (HEMS) manage the local energy resources allowing better visibility of the production and consumption data to the prosumer. Digitalization is a central enabler for development in the energy system and new business models. While technology development is still necessary in many areas, the technology is already widely available and becoming more affordable for prosumers. Data privacy and security as well as other cyber threats have been raised as concerns, and management of consumption and production data safely requires development of both technical and legislative solutions.

Economic drivers including (PV or other) system cost, energy prices, rate structures, and potential financial gains are a key consideration when consumer considers starting prosumption. Initial investment for energy generation system and expected payback time will be a factor in consumer decision-making, for example, related to solar PV equipment or EV which, despite declining price levels, still are substantial investments with relatively lengthy payback periods. In addition to cost-benefit analysis of investment, prosumers also expect other economic gains, for example, savings in their energy bill and compensation for the electricity feeding into the grid.

Energy consumer and prosumer behavior cannot be explained solely by economic factors as people do not generally act rationally, the way traditional economists define it. Various behavioral drivers including values, norms, beliefs, and motivations have been suggested to steer consumer decision-making. For example, pro-environmental values have been studied as one of the driving forces behind consumer behavior by, e.g., Ajzen (1985) and Stern et al. (1999). Diffusion models (Rogers 1995) and technology acceptance model (TAM) (Davis 1989) on the other hand study adoption of new technologies, such as RET. Ease of use and availability of turnkey solutions have been found important in adoption of complex technology solutions (e.g., Kotilainen and Saari 2018). Intrinsic and extrinsic motivations (Ryan and Deci 2000) have been studied in the context of value co-creation, and it has been found that importance of intrinsic motivations is significant in consumer engagement (Füller 2010).

In addition to technological, behavioral, and economic drivers, policy and regulation are commonly agreed to have a significant influence in the growth of prosumerism. Policymakers and industry experts agree that macro-level policies in the form of incentives, taxation schemes, and legislative enablers are needed in order to boost consumer adoption in the early phases of diffusion of environmental innovations. Solar PV, electric vehicles, and smart meters have all received support of some form from most governments, but the level of policy push varies. Different policies have been found to be effective in different contexts. Policy mechanisms can be categorized as command-and-control, economic, and soft instruments (Vedung 1998). The command-and-control policies are mandates, laws, or regulations. The economic incentives are efficiently boosting diffusion through lowering the investment threshold in new technologies through, e.g., tax exemptions, purchase subsidies, or grants. Furthermore, the soft instruments include information and education campaigns, public procurement, and voluntary approaches that are aimed to improve public awareness and acceptance of new technology solutions. Regulatory instruments can be used to constrain or enable prosumer activities. The main economic policy instruments for boost prosumerism include net metering, feed-in tariffs, investment subsidies, tax exemptions, dynamic pricing (TOU), and regulations (e.g., Ramirez et al. 2017).

- Feed-in tariff (FIT) and feed-in premium: FITs are a form of incentive; they are long-term contracts that guarantee the prosumers a specific tariff that is set above the market rate to encourage the excess energy feed-in to the grid. FIT has been an effective way to boost microgeneration.
- Net metering: Prosumers may feed excess energy to the power grid and be compensated for the amount provided in their electricity bill. In practice, this means the prosumers are compensated at the retail price. This means that the utility pays higher rate for the excess energy compared to their wholesale price from other energy market sources. Net metering has been used to boost distributed generation in several markets.
- Purchase subsidies, in the form of grants of tax deductions, are applied to generation equipment purchases and instalments to improve the payback time of the investment. Solar PV is reaching grid parity (or socket parity) which suggests that public investment aids can be phased out in the next years.
- Taxation of self-consumption is a controversial topic, and states have taken different approaches to implement taxation. In most cases self-consumption is not taxed. Some countries, for example, Spain, have introduced self-consumption tax to keep the prosumer base in control.
- Furthermore, solar access laws that protect buildings with solar installation by prohibiting any new buildings from blocking their solar access are in place in some jurisdictions (Kettles 2008).

While effective in boosting the diffusion of RET, policy interventions have been criticized to create unfair market conditions, and policymakers and energy industry experts both agree that policies should be phased out once the desired level of diffusion has been achieved. Figure 3 depicts key enablers, drivers, and prosumption activities.

Despite declining RET price levels and international and national policy efforts to enable small-scale energy prosumption, the prosumer adoption is still in early market phase in most regions; a prosumer revolution is yet to occur. Key barriers for prosumer mass movement reflect the same categories as the drivers and enablers: for example, low insolation or lack of roof space for solar PV installations; technology barriers such RET perceived as difficult to use and lack of availability of turnkey solutions; economic barriers such as low energy price levels or rate structures with emphasis on fixed fees; behavioral barriers such as lack of interest or social acceptance of RET and regulative barriers such as lack of feed-in tariffs or net metering; and tax on self-consumption or regulation that prevents energy sales (e.g., Rickerson et al. 2014).

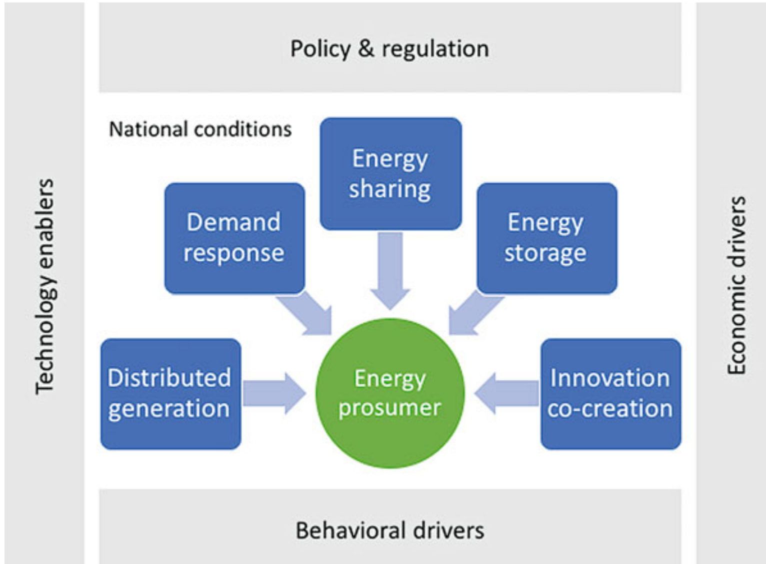
Prosumer Influence on Energy System and Sustainability

While emergence of prosumerism has several benefits to environment, economy, and society, the rising number of prosumers also poses challenges. This entry discusses consequences of increasing energy prosumerism to the energy system and sustainability.

Growing Prosumer Base Impact on the Energy System

Prosumers are new actors in the energy markets and their activities increase the use of RES and DG. On-site power generation helps reducing losses that take place during transmission and distribution, lower the need for increased transmission and distribution capacity, increase local community resilience in the absence of central power system, and offer economic opportunities for individuals and local communities. Furthermore, increased use of RES helps reducing emission globally and locally. Besides several benefits of energy prosumerism, it also poses at least two broad

Energy Prosumers' Role in the Sustainable Energy System, Fig. 3 Prosumer activities and enablers



categories of challenges to the current energy system: commercial and technical.

First, the prosumers, and other new entrants such as aggregators and service providers, shake the status quo of the energy industry. Incumbent energy companies that are mostly large and long-standing power generators or utilities now face new kind of competition, and potential loss of revenue, that is in many markets backed up by public policy-induced subsidies. Prosumers hence face inertia from the energy industry companies in the form of resistance against changes in regulations that enable or incentivize prosumption. Self-generation and using energy in off-grid mode means less and less paying customers for the utilities. Fears exist that this could lead to a cycle of rate increases for the rest of the consumers causing even more self-generation to begin and eventually lead to a "utility death spiral" (e.g., Laws et al. 2017).

Besides the incumbent companies, other consumers may be affected in the form of increased energy rates. Cross subsidization and cost-shifting between prosumers and consumers, i.e., the question whether prosumers are paying their share of the energy infrastructure, have been raised as an issue: when prosumers are incentivized for the energy they sell, normal energy consumers may be the ones who pay the bill in terms of increased energy and distribution charges (Eid et al. 2014). There are concerns that a division will arise between those who can afford to self-generate and those who cannot. Furthermore, tax authorities may experience loss of tax revenues as a side effect of increased prosumption.

Second, the energy system also may encounter technical challenges due to rapidly increasing volumes of intermittent energy supply to the grid. Electricity system has traditionally been based on centralized energy generation based on large power plants with predictable outputs. Energy grid needs to remain stable and balanced in terms of generation and demand, and thus predictability is important in the management of the system. Stricter environmental regulations mean that adding traditional generation capacity is less viable, thus shifting focus to DG and RES. Inherently intermittent supply of RES makes its predictability hence much harder. Besides load forecasting problems and capacity management, prosumer base growth can pose technical problems to the grid that create quality and reliability issues, including overvoltage conditions, congestion issues, back-feeding into the circuit, stability issues, as well as system planning challenges (Rickerson et al. 2014). Furthermore, increased amount of data collected, transmitted, and analyzed creates data privacy and security concerns.

Commercial challenges to incumbent energy companies, tax authorities, and ratepayers can be addressed, for example, through phasing out subsidies as soon as desired outcomes have been achieved, by developing new business models and investing in innovative solutions to create new business opportunities and revenue streams. There is growing body of research to address the technical challenges of increased DG based on RES and prosumption. Some of the solutions to the address the technical issues are, e.g., increasing capacity of the power lines, technical upgrades to the power grid, developing more effective flexibility and DR schemes, setting safety standards for grid feed-in, building storage capabilities, addressing data security, and investing in improved data utilization and forecasting capabilities (e.g., Rickerson et al. 2014).

Energy Prosumerism and Sustainability

Energy prosumers are anticipated to contribute to diverse aspects of sustainable development. Sustainable development (SD) targets to achieve long-term stability of the economy and environment achievable through the integration of economic, environmental, and social concerns (e.g., Dernbach 2003).

Prosumerism can contribute to environmental sustainability in at least three ways: first, prosumerism increases the use of RES as most of the energy produced by prosumers is renewable energy. DG, or microgeneration, based on RES has clear environmental benefits, perhaps the most important being that it helps in reducing the overall greenhouse gas emissions. By investing in RES to improve energy access, it is possible to avoid increase in the global emissions (WOE 2017). In addition to global emissions, cleaner energy reduces local particle emissions which in turn contributes to reduction of health-related issues of pollution. Second, prosumerism supports achieving better energy efficiency: when energy is locally produced, stored, and consumed, less will be wasted. Better energy efficiency in turn lessens the demand to energy generation. Third, prosumerism can contribute to the creation of pro-environmental innovations which indirectly helps finding more environmentally sustainable ways to produce, consume, and share energy (e.g., Kampman et al. 2016; Masera and Couture 2015).

In addition to its contribution to environmental aspects of SD, energy prosumerism can contribute to social and economic sustainability. First, prosumerism enables improved energy access in rural areas where electricity grid is not available or is unreliable. The number of people without access to electricity fell to 1.1 billion in 2016 from 1.7 billion in 2000. Despite the progress, the electrification rate in sub-Saharan Africa is currently only 43% (WOE 2017). Renewables are seen the way to further increase the energy access, especially in the rural areas in the developing world. Improved energy access in turn has multiple positive effects on the development of local communities in the form of better opportunities for businesses to develop and additional revenue streams for individuals. Energy poverty is a social problem affecting those with no access to affordable energy, be it electricity or heat (Pye and Dobbins 2015). While mostly predominant in the developing world, energy poverty exists also in the developed regions (WOE 2017; Pye and Dobbins 2015). Prosumerism can contribute to reduction of energy poverty by energy projects in communities without access to electricity or district heating. Prosumerism helps increasing the income of vulnerable households and the energy efficiency of buildings (Bertrand and Primova 2018).

Second, once the initial investment is recovered, self-produced energy is highly affordable. Energy sharing or selling back to the grid can help reducing energy bills or even gain additional income. Sustainability effects of energy sharing can be approached through sharing economy, or collaborative consumption, which is claimed to have multiple sustainable environmental and social impacts (e.g., Heinrichs 2013). Sharing economy reduces overall production that has been referred to as a balancing trend to consumerism (Botsman and Rogers 2010). For example, sharing energy using P2P platforms increases efficient use of renewable energy resources and enables social and economic benefits for both sellers and buyers of energy.

Third, the outcome of value co-creation is to boost development and use green innovations/eco-innovations. Another way to look at sustainability impacts of value co-creation with prosumers is through "green socio-technical niches" (Smith 2007) that can produce sustainable innovations that can later be adopted by regime and become widespread practices.

Conclusions

SDG 7 calls for: "ensuring universal access to modern energy services, improving energy efficiency and increasing the share of renewable energy. To accelerate the transition to an affordable, reliable, and sustainable energy system, countries need to facilitate access to clean energy research, promote investment in energy infrastructure and clean energy technology." Energy prosumption can contribute to multiple aspects of the SDG 7 (see also):

Affordable energy: With decreasing price levels for energy generation technologies, such as solar PV, locally produced and consumed energy is highly affordable.

Improved energy access: Prosumerism improves energy access by enabling rural communities without access to a reliable power grid to self-produce energy for their own needs.

Improved resiliency in communities: Improved energy access helps local communities develop and improve the livelihood of their inhabitants and economy.

Improved energy efficiency: Prosumerism contributes to energy efficiency through their participation in demand response programs and by storing and selling excess energy they produce.

Increased use of RES reduces pollution: If energy prosumerism becomes as widely adopted as predicted, it will significantly increase the share of renewables in the energy system. Prosumerism supports availability of sustainable energy for all, including the developing countries.

Environmental activists have been campaigning to put a halt to ever-expanding consumerism which may be seen as having a damaging impact on the environment. To meet the growing demand for goods, industries are using extensive amounts of water, energy, and raw materials to develop products. Consequently, poor working conditions may result from extensive production of goods in the developing countries. Contrary to consumerism, energy prosumerism could potentially have a positive, and a balancing, effect through improved energy efficiency, increased use of clean energy sources, introduction of sustainable energy innovations, and improved living conditions and financial development in communities. At its best, energy prosumerism conserves natural and human resources instead of exploiting them and enables sustainable economic growth that supports the vulnerable communities.

Cross-References

▶ Micro-Grids

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