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Review

The Energy Transition as a Super Wicked Problem: The Energy Sector in the Era of Prosumer Capitalism

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Abstract: The main objective of this paper is to demonstrate that the energy transition as part of prosumer capitalism is a socio-economic process whose complexity increases over time, which makes it an example of a super wicked problem. It comprises many new phenomena emerging spontaneously, and often unpredictably, in the energy markets. The main contemporary challenge involves such an energy sector transformation which will prevent climate change and will ensure the sustainable development of the global economy. However, this requires solving a large number of sub-problems in areas such as legislation, energy distribution, democracy, and cybersecurity. Therefore, this is a multidisciplinary issue. Moreover, the situation is complicated by the frequently omitted fact that energy transition is not part of the standard capitalism model, extensively described in handbooks and scientific literature, but it is conducted as part of a new economic system—prosumer capitalism, which has not been properly explored yet. However, a solution to this super wicked problem has to be found soon, as the energy system may be threatened with complexity catastrophe, which denotes exceeding the upper complexity limit associated with the breakdown of its adaptability. Therefore, developing effective techniques for alleviating the complexity catastrophe, including redefining the change management and complexity management methods to the global scale, becomes the top priority among the tasks faced by science.

Keywords: energy transition; super wicked problem; prosumer capitalism; energy policy; climate change; renewable energy; energy prosumerism; complexity catastrophe; change management; complexity management

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1. Introduction

The prosumer model is highly useful in the energy transition, and its role and importance are greater than is commonly thought. It leads to a gradual transformation of the whole global economy and to the emergence of a new form of capitalism, called prosumer capitalism [1–3]. This stems from the fact that energy is at the base of each economic process. The initial parts of the paper present a review of the most popular definitions of prosumer and prosumption, beginning with the first concepts proposed by Alvin Toffler to the contemporary meanings of the words. The development of data communication technologies and widespread digitalization of the economy has unleashed the prosumer potential of societies and has led to the third great economic revolution in the history of mankind—the ICT revolution, which is the aftermath of the two earlier revolutions: the agricultural and the industrial [4]. Thus, traditional prosumption has been transformed into digital, which has accelerated the development of the renewable energy markets and their integration with traditional, fossil fuel-based markets. Moreover, digitalization enabled the decentralization of the green energy sector and, in consequence, a gradual departure from monopolies in the energy sector. At the same time, digitalization favors the electrification of many important sectors of the economy, especially transport and heating, which can contribute significantly to carbon dioxide emission reduction [5]. These changes have made it necessary to replace the old management principles and business models with new ones.

Therefore, the development of Toffler's research approach, called wikinomics, based on four principles and seven business models, has been discussed [6,7]. The principles include openness, peering, sharing, and acting globally, whereas the models include peer pioneers, ideagoras, prosumers, new Alexandrians, platforms for participation, global plant floor, as well as the wiki workplace. Wikinomics is based on digital prosumption, as everything else depends on it.

The next part of the paper focuses on prosumers as chief players in the energy market, and it describes the motives that encourage them to engage in economic activity. It presents their relations with the incumbent energy companies and the methods of participation in the markets and the potential for affecting them. It was necessary to define the new challenges faced by the prosumer energy sector in such fields as jurisdiction, distribution, democracy, and cybersecurity. Issues related to the development of smart grids and their effectiveness in the context of the Jevons paradox were also presented. Moreover, attention was drawn to energy prosumerism, which creates a framework for studying many new issues related to distributed generation, such as energy justice, energy citizenship, energy democracy, and energy poverty. Furthermore, the macroeconomic effects of prosumer activities and the development of new ways of organizing the economy were explained, with the gig economy and sharing economy as the best examples. Subsequently, the energy sector regulation methods were considered, given the differences between the modern and traditional electricity policy, stimuli that encourage people to become prosumers and democratic experimentalism.

According to scientific literature, the energy transition, which is humanity's response to climate change, is a process whose complexity increases over time. This is caused by a growing number of interdependencies between the major systems: social, legal, economic, and climatic. The study has shown that the energy transition creates an extremely complex, interrelated system of phenomena, described by various scientific disciplines, which is why it should be regarded as a super wicked problem. This hinders the reconciliation of two mutually exclusive socio-economic challenges, i.e., sustainable development of the global economy and elimination of the anthropogenic greenhouse effect. There is an additional difficulty in that the challenges appear as part of the new economic system, called prosumer capitalism, which has not yet been fully explored. When defining the system, Ritzer points out that its characteristic feature is a phenomenon called synergistically double exploitation [3] (pp. 82–86). In this case, the economic development is based on the doubly unpaid labor of people, who usually exist in two roles in the contemporary world: as workers and as prosumers. This results in an uncontrolled transfer of surplus value from societies to large enterprises and to international corporations. Today, this is particularly true for users of social media platforms, whose spontaneous and unpaid activity not only generates powerful profits for multinational corporations but also strengthens their economic and political power. Moreover, an energy system includes a similar phenomenon, called cross-subsidization, which involves the uneven distribution of the utility's fixed costs between prosumers and traditional consumers, to the disadvantage of the latter. It is probable that in future, prosumption processes can change from an economic development stimulus to a barrier. Incidentally, prosumer capitalism, in Toffler's terminology, forms the Fourth Wave of civilization development, which is also called the Connected Society [8,9].

A fundamental research gap in the energy transition literature is the overlooking of its complexity arising as a result of interactions between elements of the entire system. Focusing on individual subsystems, such as society, the environment, legislation, energy and environmental policy, distribution processes, the development of energy democracy, and technological progress, causes one to lose sight of the holistic picture of the phenomena. Meanwhile, we are dealing with a complex adaptive system that is inherently open and in which there are dynamic networks of interaction. This makes the energy transition as a whole evolve to the extent determined by the emergence and the edge of chaos. Emergence is the ability of a system to create orderly collective phenomena, the description of which is only possible at a level higher than the description applied to the constituent elements. The edge of chaos, on the other hand, is the distinguished state of the system located between periodic behavior and chaotic behavior, where its computational power is at its maximum. Near the edge of chaos, the system's complexity is nearly optimal, and its adaptability is at its highest. This article proposes a holistic view of energy transition, while maintaining a detailed description of its key components and the environment in which it occurs.

The research used the method of a systematic review of scientific literature on energy transition, which involved using the entire internet space. This means that it was not limited to specific literature databases, but the information was collected from a wide variety of sources. However, the scientific regime was strictly adhered to, which was to select only those research works that dealt with the most important elements of the modern energy system and the interdependencies between them. Special attention was paid to those subsystems that play an important role in generating the dynamic complexity of the entire system.

A combination of all the issues discussed in the paper shows that the global socio-economic system may soon find itself at a critical point associated with a complexity catastrophe. This is a certain system complexity limit, and crossing it breaks down the system's adaptability. Hence, there is a need to develop solutions which will restrict the complexity of processes in the energy sector. Therefore, developing proper methods of avoiding a complexity catastrophe should be one of the research directions which may be helped by redefining two approaches in the organization science to a global scale: change management and complexity management.

2. Prosumption as the Basic Market Force in the Modern Economy

2.1. Definition of Prosumption

The term "prosumption" is a portmanteau of production and consumption. It refers to a process where a consumer takes over some of the activities previously performed by a producer, usually by directly involving themselves in the design and production of various goods or services. This phenomenon was identified as early as in 1972 by Marshall McLuhan and Barrington Nevitt, who noted that the development of electric-information technology had made it possible to combine the roles of consumers and producers [10] (p. 4). As such, the prosumer is a new form of economic entity, who not only consumes but also designs, produces, and markets a given good or service. In other words, a prosumer leverages its innovation and creativity potential to produce goods/services.

The subject of prosumption was explored further in 1980 by Alvin Toffler, who posited that the economy is divided into two sectors [4] (pp. 282–305). Sector A comprises unpaid work performed by people to fulfill the needs of themselves, their families, or even their communities, whereas Sector B relates to the production of goods or services for sale or exchange. This classification shows that the officially acknowledged and valued economy—sector B—is complemented by another, invisible economy—sector A. Furthermore, the production of goods and services for private use lays the groundwork for the economic activity carried out by society, and thus, sector B could not exist without sector A. According to Toffler, prosumption at a time of information technology revolution—designated "the third wave" by Toffler himself—is, at its core, the shift of production from sector B to sector A by the people. This is directly coupled with a reduced role of the market in the economy—de-marketization. Prosumption is mainly driven by its benefits to the prosumers, stemming from the law of relative inefficiency. This law holds that as the production of goods becomes automated, the per-unit cost of these goods falls, thus increasing the relative cost of handcrafts and non-automated services. This makes production for one's own, private use a more cost-efficient proposition, thus spurring the growth of sector A. Among the many other factors that drive people to prosume are: rising inflation, the dissolution of second-wave bureaucratic service-provision systems characteristic of industrial civilization, the appearance of new, third-wave information technologies, and the rise in structural unemployment.

Prosumption leads to the externalization of the labor cost, meaning that people who produce goods/services for themselves take up part of the labor that had been originally provided by producers. This labor is mostly unpaid, and thus increases profits for some businesses and precipitates economic exploitation of prosumers.

2.2. Prosumption as the Basic Business Model of Wikinomics

Wikinomics is a field of research that discusses the impact of information technology on modern economic processes. As part of it, new principles for conducting business in the modern world and new models of global cooperation were identified. Digital technology can now be considered a top technique in the sense of Hicks, i.e., one that provides the highest rate of return and enables the introduction of the economy on a balanced growth path with the maximum rate of growth [11]. This explains the high, unprecedented economic growth and development that has occurred in recent decades in many countries of the world.

There are four principles of wikinomics: openness, peering, sharing, and acting globally. These principles are the most important factors of economic growth and development in the digital economy. Openness involves companies sharing part of their resources with the business environment in order to obtain external sources of creativity and innovation. Partnership is associated with the spontaneous transformation of some economic organizations from hierarchical to horizontal. Sharing means a less restrictive policy of companies regarding intellectual property, which applies, in particular, to patents and copyright. Information technology has removed existing barriers between business entities and enabled them to operate on a global scale [6,7].

An important achievement of wikinomics is to identify seven models of mass collaboration that have radically changed traditional business strategies. These include [6,7]:

1. Peer pioneers—volunteers creating innovative ventures outside the market sector;
2. Ideagoras—modern search systems for business partners and original scientific research experts;
3. Prosumers—people who are both producers and consumers;
4. New Alexandrians—people's cooperation to multiply, accumulate, systematize, and share all knowledge of humanity;
5. Platforms for participation—websites with relevant products and information technology that encourage large communities of partners to collaborate in order to create new products;
6. Global plant floor—production of goods and services as part of global cooperation;
7. Wiki workplace—meritocracy abolishing the hierarchy in the enterprise and connecting internal teams with external networks.

The principles and business models of wikinomics, which developed as a result of mass and spontaneous collaboration of people, led to the rapid growth and economic development of the entire global economy. However, one should not forget that this progress also has a dark side. This is due to the fact that the well-known phenomenon in classical economics, namely, the exploitation of people in the processes of production and distribution of goods and services, has been forgotten.

2.3. Types of Prosumption

2.3.1. Alvin Toffler's Three Waves of Prosumption

Prosumption is a complex and multi-dimensional topic, and has thus been relatively poorly explored in economics. The first classification of prosumption was put forward by Toffler himself. His taxonomy is based on characteristics of the three economic waves of humanity's economic history, which he analyzed. Using this criterion, he distinguished three forms of prosumption [4]:

1. First-wave prosumption of agricultural societies, where goods and services were mostly produced for private use, with only a small proportion exchanged between

people. Obviously, this impeded the growth of goods and service markets. In this period, sector A was relatively large, whereas sector B was far less prominent;
2. Second-wave prosumption was characteristic of the industrial society largely geared towards producing for trade, with minimal production for self-use. This was the reverse of the first-wave trend: consumption functions and production functions became largely separated. Sector B grew to gigantic proportions, which meant that Sector A became imperceptible to many economists. The progressing industrialization gave rise to an international trade network, a trend which Toffler named "the marketization of the world";
3. Third-wave prosumption appeared hand in hand with the informational technology revolution and restored the balance between Sector A and Sector B through the emergence of a new lifestyle, one based on production for exchange and production for self-use in roughly equal measures. Toffler argued that the market could no longer grow by absorbing new countries—that, on the contrary, it would start shrinking. This would bring about the aforementioned de-marketization—a reverse of the trend present during the second wave. Nevertheless, qualitative changes and development will continue, and the (necessarily reduced) market will give rise to a trans-market civilization which will deal with solving entirely new problems. The fourth wave is, therefore, to be expected.

By making this distinction, Toffler suggests that the renewed significance of sector A—brought on by the information technology revolution—will not only change the very underpinnings of our economic system, but also our belief system. A new, more holistic conception of an economy would be needed, one which would describe the phenomena of sector A and how they relate to sector B. The entire economic terminology would have to be redefined, as explaining the relationships between unmeasured production/productivity in sector A and measured production/productivity in sector B would require brand new models, metrics, and criteria [12]. Traditional measures of production, such as the gross national product, would slowly become obsolete if they fail to incorporate data on sector A economic activity. A fresh perspective on the problem of prices and costs would also have to be adopted, since the effectiveness of prosumption in sector A would affect the costs of private and public enterprises in sector B. Efficiency is currently determined by simply comparing different methods of producing a given good or service and is not compared across sectors, i.e., production in sector B is not measured against the corresponding efficiency in sector A. The rising importance of prosumption was also destined to cause inevitable changes in the belief system of a trans-market civilization. The development of the markets during the second wave gave rise to vulgar materialism and the preconception of economic stimuli as the primary force shaping people's lives, as expressed in marriage contracts and various social contracts. However, the market is more than just the economic structure—the psychosocial structure is a part of it as well. Therefore, in a trans-market civilization, we should see—according to Toffler—wider shifts in the worldview, or even new religions [4] (pp. 300–305). Many of these predictions have proven accurate, especially with regard to energy prosumption, as discussed further in the paper.

2.3.2. The Six Archetypes of Prosumers

Prosumption is a multi-faceted phenomenon and a focus of decades of research, with a wealth of studies detailing its taxonomy. Even so, the subject has yet to be fully explored. The most recent classifications distinguish between six archetypes of prosumers [13]:

1. DIY (do it yourself) prosumers—individuals who create goods and services exclusively for private use, without paying an external entity for them;
2. Self-service prosumers—prosumers who can perform partial self-service using technological tools, for example by repairing a bike or a computer by themselves, and thus co-creating value;
3. Customizing prosumers—prosumers who personalize products to better serve their own needs, especially with regard to entertainment, travel, or clothing;

4. Collaborative prosumers—individuals who provide for their own needs or the needs of others and thus create value without profit for any intermediary, e.g., by developing open-source software;
5. Monetized prosumers—prosumers who create value accessible to others via a commercial entity without being formally rewarded for their activity, e.g., through their activity on social media platforms;
6. Economic prosumers—individuals who receive formal incentives from commercial entities for the value they create for others, as best exemplified by prosumers who produce electricity for their own use and for sale.

2.3.3. Cooperation of Prosumers with Other Market Participants

Classifications of prosumption are increasingly being adapted to the changing markets and economies. In many cases, prosumers may well be categorized according to how they cooperate with other market entities [14,15]. Using this criterion, three types of prosumption can be identified [16] (pp. 51–57):

1. Individual prosumption, which is when a given prosumer does not engage in any cooperation whatsoever with other market entities, being completely independent from them and self-sufficient in their own activity;
2. Intra-prosumption refers to a collective form of activity where the actor is part of an organized group of prosumers and engages in participatory design or co-production (exclusively within the given group of prosumers);
3. Inter-prosumption occurs when a group of prosumers and a producer work together to develop new products/services or improve existing ones, for example, via social media. Inter-prosumption is further divided into its simple and complex varieties.
    - Simple inter-prosumption may take forms such as: lead users [17], the individualization (de-massification) of products and services [4] (pp. 271–274), production of a commodity by a producer, using information and starting material supplied by the prosumer, self-assembly [4] (pp. 294–295), and sharing a product with a business to perform a service (bike-sharing, car-sharing);
    - In contrast, complex inter-prosumption occurs both within a prosumer group and a producer group, with the two collectives also working together. The field of renewable energy production offers an example of public prosumers in the form of autonomous energy regions—demarcated areas of rural and agricultural land [18–21].

Notably, these two above taxonomies are largely in line with Toffler's views of the subject. Essentially, all these types of prosumption can be associated with one of the three waves of civilization development. It is, therefore, clear that the different types of prosumption can overlap, further speaking to the challenges faced by modern researchers attempting to define prosumption precisely. Producers of electricity who self-consume a portion of it and feed the excess to the power grid could be classified either as monetized prosumers or as entities engaging in intra-prosumption/inter-prosumption.

2.4. The Exemplification: The Interdependencies between Sector A and Sector B in the Polish Economy

Polish academia has seen a number of studies on prosumption in recent years, but virtually all of them focus on the market sector. Most of the analyses agree that society is showing a strong propensity toward prosumption, particularly in the banking services [22], food [23], and energy sectors [24]. Rather than a phenomenon exclusive to the youth (Generation C)—i.e., people born after 1990, reaching maturity after 2000, and entering the labor market after graduation—prosumption has been shown to also extend to the elderly, who are interested in pursuing energy prosumption [25,26]. It has also been demonstrated that prosumption is an important element of innovation marketing [27]. Of the literature analyzed for this paper, only one study indicated low societal interest in commercial prosumption [28].

The work by Szymusiak corroborates our earlier assumption that prosumption is more pervasive in Poland than in more developed countries such as Germany, with the added finding that individual prosumption is more popular in Poland [29], whereas Germans gravitate towards its collective forms (intra-prosumption and inter-prosumption) [14] (pp. 263–264). However, these results are from 2012, when the public administration sector was inelastic, poorly digitalized, and ill-suited to harnessing the prosumption capacity of the society, resulting in its sluggish response to changes in the private sector. Furthermore, there were very few incentives to energy prosumption. Though the Polish government has since been more successful in tapping into societal appetite for prosumption, especially with regard to the energy sector, its hand was forced by external factors, such as its obligation to uphold international agreements pertaining to the energy transition. While these changes promoted a new focus on developing collective forms of prosumption, the current situation is far from satisfactory. There persists a disparity between the private and public administration sectors in terms of harnessing the prosumption capacity of the society, and this asymmetry hinders the growth and development of both individual markets and the economy at large [30]. There is still not enough research on prosumption in public administration.

3. Prosumption in the Energy Sector

3.1. The Energy Prosumer as an Active Market Participant

3.1.1. Definition of the Energy Prosumer

Until recently, the supply side of the energy market was highly centralized, as it was dominated by large companies, i.e., generators and service providers. As such, consumers tended to be the passive segment of the market. As renewable energy technologies developed, this situation began to gradually change, primarily due to the emergence of relatively cheap photovoltaic solar panels, allowing many consumers to become energy prosumers—a term used to describe market actors who combine the characteristics of energy consumers and energy producers. When people are driven to prosume, it is usually due to economic factors—they hope to reduce utility bills, while also making a net profit. Energy prosumers may conduct commercial activity in one of three ways: engage in distributed generation (self-production and sale of electricity), provide energy storage services, or participate in energy efficiency and demand response programs. Energy efficiency is achieved when the same service is performed using less energy, whereas demand response programs aim to change the normal electricity consumption patterns of end-use customers on a voluntary basis, as energy prices change over time. This is accomplished by utilities charging higher prices for electricity at peak times or paying customers for reducing their electricity usage at certain times of day (under appropriate contracts). Demand response programs can function both on retail markets and wholesale markets [31].

In the European Union, energy prosumers are referred to as active consumers, though the terms are more or less interchangeable in meaning [32]. An "active consumer" is defined as [33] (p. 139):

> *a final customer, or a group of jointly acting final customers, who consumes or stores electricity generated within its premises located within confined boundaries or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy efficiency schemes, provided that those activities do not constitute its primary commercial or professional activity.*

Active consumers play a key role in the European energy transition—the switch from centralized, fossil fuel-based energy generation to the production of electricity from distributed renewable sources. The idea is that renewable energy prosumers boost competition on the electricity market by increasing the number of energy suppliers and curbing the economic power of large energy companies [34].

3.1.2. Barriers to Demand Response

The member states of the European Union are incentivized to promote and facilitate participation in demand response programs. Nevertheless, deploying such programs in prosumer markets may not be without problems. There are two types of barriers to demand response [35,36]:

1. Barriers to implicit demand response emerge when the consumer response to price change is disrupted by certain factors, e.g., lack of access to a dynamic pricing contract or lack of a smart meter (preventing two-way real-time communication);
2. Barriers to explicit demand response may be legal or logistical. Legal barriers arise when demand response is not allowed in certain markets, whereas logistical barriers emerge when technical demand response and aggregation is permitted by the applicable regulations but cannot be used due to particular market requirements, such as product definitions, excessive minimum bid sizes, or aggregation limits.

3.1.3. Motivators That Drive Customers to Be Active in the Energy Market

Recent years have seen substantial rise in the global number of prosumers who use photovoltaic panels to produce electricity for their own use and for sale. The main reason for households installing solar panels is to increase self-consumption, since the self-generated electricity may be cheaper than energy from the grid, which is subject to various taxes and fees. In other words, energy prosumers aim to reach a grid parity. The structure of the electricity price is fairly complex because, in addition to the charge for the energy consumed, it also includes a number of other components that are divided into fixed and variable ones [37] (p. 14). In general, the energy production costs make up only 36% of the on-grid electricity charge paid by the final consumer, an additional 26% being the network costs, and the remaining 38% consisting of taxes and levies [32]. In Poland, the primary motivating factors driving customers to engage in prosumption are the potential savings and lower electricity bills [38]. Utilization of battery storage systems may prove to be the next step towards energy self-sufficiency of households by reducing their dependence on the electricity grid. Simultaneous production, consumption, and storage of electricity is referred to as prosumage [39,40]. It has been shown that the achievable self-consumption rates for a 4 kWp PV system can be boosted by installing a battery, though the number of persons in the household and the installed storage capacity are also a factor. The cost-efficiency of prosumage is maximized when the ratio of battery capacity to peak power capability of a solar panel is 1:1 (kWh/kWp) [41]. Even an electric car battery can serve as a domestic backup power source, forming a vehicle-to-home (V2H) system when connected to the grid [42]. This solution can certainly support self-consumption.

3.1.4. Types of Energy Prosumers

Prosumers active in the energy markets form a highly diverse group, which is why it is difficult to neatly categorize them. Energy prosumers are most commonly classified according to the role they play in the market. With this criterion in mind, prosumers are divided into residential, commercial, and industrial prosumers [42]:

1. Residential prosumers mostly comprise those who live in dwellings supplied with power for regular domestic use, such as lighting, heating, cooling, and cooking. These include households, apartment buildings, housing associations, cooperatives, and collectives;
2. Commercial prosumers use energy to meet both their own needs and the needs of the community. This group includes businesses of different sizes, universities, department stores, shopping malls, hospitals, offices, and sport facilities;
3. Industrial prosumers include industrial operators which use on-site renewable energy systems to self-generate power for own use and supply the excess to the national grid or sell it to the local community [43]. This group mostly encompasses manufacturers and producers such as factories, mines, mills, industrial plants, and farms.

These three groups of consumers can be easily distinguished by the size of their energy system. Residential prosumers have an installed capacity limit of no more than 10 kW, commercial prosumers encompass installations over 10 kW and below 250 kW, while industrial prosumers employ installations of 250 kW and more [44,45]. There are also other ways of classifying energy prosumers—for example, by the type of energy they generate, the source of energy they use, or by their relationship with the power grid [42,44]. Importantly, prosumers may organize themselves into groups or communities, which frustrates attempts to classify them. Such organizations are also considered prosumers, as they often operate as single entities in the energy market. Prosumers may also establish virtual power plants that integrate multiple types of distributed energy resources to ensure reliable overall power supply [46,47].

3.1.5. Relations between Energy Prosumers and Incumbent Energy Companies

The emergence of prosumers in electricity markets has forced energy companies to rethink their traditional business models. The relations between these two groups of entities should be considered to be a unique type of stakeholder relations—co-producing prosumers behave fundamentally differently than consumers. Power companies initially enjoy a substantial advantage over the prosumer, owing to their ability to manage the power grids. In contrast, prosumers need grid services to purchase and sell electricity. Studies have demonstrated that the relations between prosumers (in their capacity as co-producers) and energy companies should be based on reciprocity, with the two groups working closely together towards the decentralized production of renewable energy [48]. Today, this relationship may even be the inverse of the original one, as energy companies have increasingly realized that competitiveness in renewable electricity generation is predicated on their ability to attract prosumers and develop constructive partnerships with them [15].

3.1.6. The Potential for Prosumers to Manipulate Energy Markets

Prosumers play a growing role in modern economic life, raising the question of whether they would be able to manipulate the power markets, whether as sellers or buyers. Modeling a market with a strategic prosumer has demonstrated that the prosumer can leverage its market power without impacting its net position in equilibrium. A prosumer in the short (long) position as a price-taker, i.e., a buyer of power from the main grid, is thus also in the short (long) position as a strategic entity, and vice-versa. Furthermore, a prosumer has influence over prices, but in terms of strategy, it is better served by assuming the role of a price-taker, rather than a strategic entity employing the Cournot strategy, as long as there is competition between other entities. Under certain conditions, the activity of the prosumer can lead to lower power prices for consumers, but at the expense of the producers [49].

3.2. Challenges Facing the Prosumer Energy Sector

The emergence of energy prosumers in the economy brought with it a number of new problems with regard to energy law and the energy regulatory system, which Jacobs describes as jurisdictional, distributional, and democracy puzzles [31,35]. In addition, there are issues related to cybersecurity.

3.2.1. Challenges in the Jurisdictional Sphere

The need to clarify legal regulations stems from the fact that energy prosumers combine the attributes of consumers and producers. This raises the question of whether they sell energy on a retail or wholesale basis, an important distinction in the context of net metering and demand response. Net metering policy is a way to encourage investment in on-site generation by paying prosumers for the electricity they supply to the grid at full retail rates, which are much higher than wholesale rates. Such incentives are thought to diminish the role of prosumers in the market, and it remains unclear whether the retail rate is the proper price in such a situation. In the case of demand response, where the price signal from the grid is intended to reduce electricity consumption, there are similar difficulties in classifying a given sale as retail or wholesale. There are doubts on whether to categorize actors who provide such grid services as consumers or producers [31]. The majority of current legal problems related to the energy transition center around four issues: the concept of prosumer, the introduction of demand response, the evolving roles of distribution system operators, and the birth of peer-to-peer trading [36,50].

The legislative processes in Poland may generate significant transaction costs, potentially discouraging prosumers from investing in renewable energy production and delaying the development of the green energy sector [51]. Despite the many favorable jurisdictional changes introduced in recent years, 45.8% of experts still consider labyrinthine regulations to be a major barrier to the development of renewable energy production, with an even larger share (72.2%) believing that further legislative changes are necessary [52].

3.2.2. Challenges in the Area of Distribution

Distribution-related conundrums stem from the divergent interests between prosumers and traditional consumers, being connected with the problem of cross-subsidization and pricing demand response. Incentives for prosumers, aimed at encouraging them to provide grid services, should not be offered at the expense of traditional consumers, especially not by burdening the latter with the prosumers' portion of fixed grid costs. These costs remain fixed, regardless of the short-term energy consumption, and are covered by a specific combination of fixed and usage-based charges. The initial financial incentives for prosumers (in the form of net metering programs) were considered necessary to overcome the cost barriers to the development of distributed generation systems. However, as the number of energy prosumers grew rapidly, distributional inequities became a potential problem. The biggest concern is cross-subsidization, which occurs when the principle of equal division of utility's fixed costs between prosumers and traditional consumers is compromised, and the latter are burdened with the larger share of the costs. Furthermore, the issue of cross-subsidization is connected to the utility death spiral [42]. Passing the increasing costs of electricity on to traditional consumers may end up creating a scenario where some of them decide to disconnect from the grid and switch to self-generation. This will increase costs for the remaining consumers, thus further encouraging others to abandon the grid. As a consequence, the utility will not have enough customers to cover fixed costs. Conversely, however, it should be noted that traditional consumers may procure a number of direct and indirect benefits from distributed generation development, including reduced peak loads or ancillary services, i.e., voltage support and reactive power.

Problems in distribution can also emerge in relation to pricing demand response, as is well-exemplified by the locational marginal price. This is the price that prosumers may receive for selling demand response into organized wholesale markets, set at a level corresponding to generation resources. This means that prosumers are compensated for each megawatt of power they have foregone, with a value equivalent of one megawatt of power generated and supplied to the grid using traditional generation resources. There is controversy on how to distribute the costs of this compensation among other energy market actors [31].

3.2.3. Challenges in the Domain of Democracy

The third type of issue relates to democracy and speaks to the need for inclusiveness in administrative processes. There are many arguments for involving prosumers in the process of shaping energy policy [31]:

- Firstly, efficient and fair administrative governance is predicated on including all stakeholders. Excluding energy prosumers from the process would mean that their major interests would not be represented;
- Secondly, if the stakeholders are able to participate in legislative processes from the very start, the proposed legal acts are more likely to be well-received and less likely to be questioned ex-post. Negotiated rule-making procedures can facilitate the exchange

of information between regulators and stakeholders and, consequently, help settle disputes and reach a consensus on proposed legal rules, which can help avoid many delays and associated costs;
- Thirdly, including prosumers in administrative procedure results in higher-quality decision-making.

In Poland, the issues of democracy related to the development of distributed power generation center around the social aspects of the energy transition, social dialogue and effective communication, solidarity and co-responsibility, as well as intensification of cooperation and synergy of actions [53].

3.2.4. Cybersecurity Challenges

Digitalization plays a strongly transformative role in the energy system, as it includes not only digitization, i.e., the conversion of analog data to digital, but also new business models of prosumer capitalism [42]. Digitalization has changed the traditional business models of the energy sector by enabling the development and integration of renewable and non-renewable energy production. This has produced new power systems boasting unprecedented complexity, with smart grids becoming their most crucial components [54]. Initially, the energy landscape had mainly evolved along the lines of an isolated and protected sector of the economy, gradually transforming into an open network, based on technologies that make use of the internet and other business networks. Furthermore, the diversification of energy sources (some of which are intermittent) and the resultant change in energy generation's structure have led to the creation of a power system that requires constant and real-time management. Balancing electricity demand and supply is only possible if the key system components have been digitalized, which is why digitalization is considered to be a prerequisite to energy transition. The rapid development of information and communication technologies has made electricity a key factor of production in modern economies. There is a certain paradox with regard to cybersecurity. Digitalization is a driver of electricity sector development and, at the same time, makes it more vulnerable. Smart grid solutions certainly bolster system efficiency and reliability while reducing costs of energy supply, but they also open up new and serious cybersecurity challenges [55]. The rapidly growing circulation of energy and information is being mediated by an increasing number of people using a wide variety of technical devices and smart software, making it much more difficult to address data security issues such as integrity, availability, and confidentiality [56]. These complex systems are represented, for example, by the U.S. power grid, often called the world's largest interconnected machine. In 2017, this grid consisted of over 7000 power plants, 55,000 substations, 160,000 miles of high-voltage transmission lines, and millions of miles of low-voltage distribution lines [57]. It should not come as a surprise that such complexity can open up a lot of potential vulnerabilities.

The electro-energetic system is a key part of the state's critical infrastructure, which includes systems composed of functionally related components in the form of buildings, equipment, installations, and services crucial for the security of the state and its citizens, ensuring the efficient functioning of public administration, institutions, and businesses. This makes the system a popular target of cyberattacks [58]. Its destabilization would be all the more dangerous due to the knock-on disruption of numerous other key sectors, including telecommunications, transportation, health care, or the water and sewage system, creating a threat to human life and health as well as a risk of significant material losses. Cybercriminals are usually motivated to act by politics, ideology, money, or moral sentiments [59]. One of the most notorious cyberattacks was launched against Ukraine on 23 December 2015 and resulted in the disruption of the energy grid, causing 6-hour blackouts which affected approximately 225,000 customers across multiple agglomerations [60]. Russia was accused of taking part in the attack, though, as of yet, no evidence has emerged that would categorically prove such involvement [61].

The progressing energy transition will require further digitalization of the energy industry, meaning that it will unavoidably keep growing more complex. As such, the risk of cybersecurity incidents cannot be fully eliminated. The combat these issues, a suitable cyberattack prevention policy will need to be developed, despite the huge legislative challenge it poses. The accommodate this need, the European Commission presented its cybersecurity strategy on 16 December 2020, with the general protection of the global and open internet as one of its primary goals [62]. Cyber insurance policies—a type of disaster insurance—may serve as a useful tool for mitigating the effects of cyberattacks "after the fact". However, this solution will not come cheap for policyholders, as insurance companies tend to set caps on cybersecurity policies, forcing utilities to increase these caps by combining policies from different insurers [63]. Reducing the complexity of energy systems still seems to be one of the best ways to protect against cyberattacks [64].

3.3. Smart Grids as a Fundamental Element of a Decentralized Energy System

Inherent to a decentralized prosumer model is a technological infrastructure consisting of smart grids equipped with innovative digital applications and smart metering systems. In the European Union, a smart grid is defined as [65]:

> *an electricity network that can integrate in a cost efficient manner the behaviour and actions of all users connected to it, including generators, consumers and those that both generate and consume, in order to ensure an economically efficient and sustainable power system with low losses and high levels of quality, security of supply and safety.*

In other words, smart grids are integrated systems that encompass not only technology, but also information, human and social influences, organizational and managerial supporting arrangements, political constraints, and appropriate legal solutions [66,67]. They are primarily intended to increase consumer participation in the energy market and increase energy efficiency through real-time balancing of this market, using tools such as demand response management. Smart grids are dual in nature, being a fusion of hardware (which stimulates the growth of prosumer energy and the development of the renewable resource market) and software (which provides relevant regulation). Smart grids also contribute to the expansion of the gig economy by facilitating the emergence of new market actors, blurring the line between producers and consumers, the employee and the self-employed, which is what Toffler refers to as the de-marketization of old structures by shifting economic activity from sector B (production for swap) to sector A (production for own use). One of the ways to optimize the operation of smart grids is to supplement them with energy storage capacity in the form of batteries or by using electric vehicles for this purpose. Smart grids must also conform to stringent security requirements, given the need to collect and process detailed consumption data as well as data relating to geo-location, tracking and profiling on the internet, video surveillance systems, and radio frequency identification systems [67] (p. 142). Consequently, they may help facilitate the achievement of the fundamental objectives of the European Union's energy policy, such as efficiency, security, and sustainability. In the near future, smart-grid energy systems will use Internet-of-Things (IoT) networks, connecting billions of smart objects such as smart meters, smart appliances, and a wide range of sensors [68–74].

Some of the crucial benefits of implementing smart grids are: an 80% reduction in costs of integrating renewable energy sources with the energy system, a 40–52% increase in the share of solar (PV) energy in the public grid, and a 15% reduction in global carbon dioxide emissions [75] (pp. 80–81). Forecasts regarding the development of smart grids around the world to 2030 envisage three scenarios with different volumes of investments [76] (pp. 304–308):

1. The best-case scenario supposes an increasing pace of smart grid development at about 30–40% annually, with total investments at around 60 billion USD;
2. The realistic scenario forecasts a growth of about 2% annually and an estimated 20 billion USD spent on investment;
3. The worst-case scenario sees a decrease of about 2% annually and a reduction in investment into smart grid technologies, falling below 10 billion USD.

When balancing traditional energy grids, utilities know what the supply is and only have to balance it with the demand, which usually fluctuates within a pre-established range. Preserving the right relationship between supply and demand required them to maintain a large reserve capacity, which did help prevent market imbalances, but also increased the overall costs and carbon dioxide emissions. In contrast, smart grids offer sophisticated means of controlling energy use, accounting for the fluctuations in the net load. Thus, the aim is to minimize the gap between total demand (load) and variable generation, demand and supply both being stochastic variables. Switching from a supply-driven to a demand-side energy policy requires that traditional risk metrics and risk management methods evolve, as well [67] (pp. 145–146).

3.4. Participation of Prosumers in Energy Markets

Recent years have seen the emergence of numerous prosumers on the energy markets, who simultaneously produce electricity from intermittent renewable resources, store it, and use home energy management and electric vehicle-to-grid (V2G) systems [42]. This necessitates the use of smart prosumer grids which support dynamic pricing, are adapted to distributed generation, and incorporate large-scale digital networking. This is not without its share of technical, institutional, economic, and social challenges, but overcoming them offers many potential benefits. Market structures can be divided into three types, according to how modern prosumers interact with the market [77]:

1. Peer-to-peer models. Such systems connect all prosumers with each other via decentralized, autonomous, and flexible peer-to-peer networks, allowing electricity producers and consumers to bid and sell/purchase energy services directly. The distribution grid usually charges a management fee as well as a tariff for distribution, which varies depending on the type and amount of the service and the distance between the supplier and the recipient;
2. Prosumer-to-grid models. These models are based on brokerage systems for microgrid-connected prosumers. These may be either prosumer-to-interconnected microgrids (where the market actors are connected to a microgrid, which in turn is connected to a larger network) or prosumer-to-islanded microgrids (where services are provided in autonomous microgrids). Each of these modes offers different incentives for prosumers. In the former, it is in the interest of prosumers to generate as much electricity as possible, as any excesses may be sold to the main grid. Conversely, for the island mode, energy services must be balanced at the microgrid level and surplus electricity must usually be limited to what can be stored;
3. Organized prosumer groups. In these models, groups of prosumers pool their resources and/or set up virtual power plants. This way, local prosumer markets can be created to support the functioning of smart cities. Such structures could give local organizations and communities a means to enhance their electricity demand management [78].

There has been a number of specific solutions developed recently to harness peer-to-peer platforms based on smart grids to trade electricity. Apart from maximizing prosumer profits, these approaches emphasize aspects such as optimality and fairness among prosumers [79,80], mitigation of power losses and prevention of over utilization of the power lines [81], complications of local demand and supply balancing [82], maintenance of prosumers' privacy [83], factors affecting the behavior patterns of individual prosumers [84], or a motivational psychology framework to help reduce carbon dioxide emissions and lower the cost of energy [85]. Peer-to-peer platforms may be adapted to work in the energy ecosystem of different countries, but there are various specific regulatory barriers that have to be overcome first [86,87]. There have also been proposals to introduce market models that integrate prosumer communities using peer-to-peer trade and residential storage with wholesale electricity markets [88].

In Poland, organized civic participation in the energy sector is facilitated by energy clusters and energy cooperatives, which exemplify renewable energy communities and citizen energy communities—the two forms of distributed-generation associations grouping market actors, as proposed by the European Union [89]. The term "cluster" has been clarified and popularized by Porter and refers to a geographic grouping of interrelated enterprises and institutions who engage in specific economic activity [90]. An energy cluster is a civil law agreement on the production, demand balancing, distribution, and/or trade of energy from renewable sources or other sources/fuels. The cluster can be joined by natural persons, legal persons, universities, research institutions, and local government bodies, which must operate in a distribution network with rated voltage below 110 kV. A single cluster (which is represented by a coordinator) cannot extend beyond the limits of a single district or five municipalities. The territorial extent of the cluster depends on the locations of grid connections for the participant generators and consumers of energy. An energy cooperative is a voluntary association of persons which generates electricity, biogas, and/or heat from a renewable energy source for the benefit of its members, while also balancing the demand for the electricity/biogas/heat. It must be connected to a local electricity distribution network with rated voltage below 110 kV, a gas distribution network, and/or a heat distribution network. Cooperatives are subject to a number of limitations. A cooperative must operate within a rural municipality, an urban–rural municipality, or with a territory of no more than three adjacent municipalities of either type. A cooperative must also not exceed one thousand members. The total installed electrical capacity must be sufficient to cover at least 70% of the cooperative's own demand and not exceed 10 MW, the total thermal power output should be less than 30 MW, and the combined capacity of biogas installations must not exceed 40 million m^3 [91–94].

3.5. The Jevons Paradox and the Energy Efficiency

One of the biggest challenges for prosumer markets is finding a way to meet the coming electricity demand, which is forecasted to increase. In other words, the question is whether smart grids designed for energy efficiency can avoid the well-known Jevons paradox, also known as the rebound effect [95,96]. In 1865, the English economist William Stanley Jevons noted that the same technological advancement which improved the efficiency of coal use in steam engines also increased the demand for coal as a relatively cheap power source. This meant that the steam engine proliferated across various industries, resulting in an increase in total coal consumption. He summarized his observation thus [95] (p. 123):

> *It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth. As a rule, new modes of economy will lead to an increase of consumption according to a principle recognised in many parallel instances.*

This paradox, when applied to smart grids, would mean that the increased energy use efficiency will also increase energy consumption, without a reduction in greenhouse gas emissions. As such, efficiency policies may be counterproductive to the objective pursued. In the context of climate change and sustainability goals, it is argued that the only way to avoid the Jevons paradox would be to introduce conservation policies that raise the fees for access to a given power supply. Such proposals include physical caps, such as quotas or rationing [97], environmental taxation [98], and emissions trading schemes [99–102].

Energy efficiency can also be viewed through a different lens—as a new type of fuel, which is sometimes referred to as the fourth fuel (after hard/brown coal, crude oil, and natural gas) or the invisible fuel. Its reserves can be increased in two ways. One is to mitigate energy waste in global and regional economic processes—for example, by eschewing the production of disposable, perishable, low-quality, useless, non-repairable products, as well as products too costly to repair (so that buying a new product becomes more economical). This would require a shift in the current trends and consumption patterns, which promote constant replacement of still functional products and equipment with new ones, as exemplified by cars and electronics. The second way is to reduce collective and individual energy consumption across all facets of society, in accordance with the maxim "the biggest innovation in energy is to go without" [103]. The fourth fuel is the cheapest of all, even compared to renewables [104] (p. 47). In the United States, the estimated cost of saving 1 kWh is 2.8 cents, whereas the typical retail fee for 1 kWh is 10 cents. In an electricity-consuming sector, saving 1 kWh can cost a mere one-sixth of a cent, meaning that the payback period for such an investment is measured in months, rather than years [105]. Energy efficiency potential in Poland is between 30 and 60 TWh/year, the equivalent of six to twelve 200 MW power units in conventional power plants that could be shut down. Increasing energy efficiency provides multiple benefits, such as energy conservation, carbon dioxide emission mitigation, and reduced energy costs. Eliminating energy waste and increasing energy efficiency of economic processes could greatly reduce global energy demand and thus reduce carbon emissions, far beyond what could be achieved by shutting down fossil fuel power plants alone [103].

In the context of energy waste, it should be noted that the embodied energy in some products is enormous. An estimated 27,780 kWh goes into producing a medium-sized car. The global production in 2015 was 72 million vehicles, meaning that the 1944 TWh of energy was embodied in these products—more than 12 times the electricity production of Poland. Doubling the service life of a fully operational car could create energy savings of 972 TWh, with a corresponding reduction in carbon dioxide emissions of 900 million tons per year. Slightly lower savings are achievable by extending the life of electronic equipment such as laptops, phones, and tablets, the global production of which consumed 278 TWh energy in 2015 [103,106].

3.6. Energy Prosumerism as a Framework for Studying Phenomena Related to Distributed Generation

3.6.1. Definition of Energy Prosumerism

The growing importance of energy prosumers in the electricity market has not only led to major changes in the energy sector but also to the emergence of completely novel socio-economic trends, necessitating a broader view of prosumption processes. The most important of these trends is prosumerism, defined as a set of social behaviors and prosumer attitudes striving to change the traditional criteria for evaluating products, standard of living, and quality of life. These new criteria take into consideration all benefits of prosumption, the material and the non-material, both in the course of production and consumption [16] (pp. 306–310). Energy is a prerequisite to launching any production process and, therefore, lies at the forefront of prosumerism. Modern energy prosumerism is a social movement facilitated by the growing participation of prosumers in renewable energy generation, which translates to numerous economic, social, and environmental benefits for the society [42]. The movement aims to move away from the centralized and monopolized energy system to a decentralized democratic energy system. Prosumerism is constantly growing in importance, which is why it has framed the efforts to study energy justice, energy citizenship, energy poverty, energy democracy, and the sharing economy [107]. These terms are related and overlapping, but still worth discussing in greater detail below.

3.6.2. Energy Justice

Of the issues related to energy justice, the availability and affordability of energy services, intragenerational equity, intergenerational equity, and responsibility are the ones most frequently cited [32]. Intragenerational equity relates to the distribution of burdens within separate generations, including the current generation and future generations [108]. Conversely, intergenerational equity concerns the distribution of burdens between the current generation and future generations—a major problem in a situation where the current generation pays the costs of climate change mitigation while future generations benefit [109]. Studies have demonstrated that energy prosumers could help achieve energy justice goals, such as access to basic energy services for everyone and responsible use of energy sources. However, this cannot happen without relevant legislation that ensures intragenerational equality [32].

3.6.3. Energy Citizenship

Energy citizenship concerns the active participation of individuals in energy generation from renewable sources, including by material engagement with the use of new technologies. Solar energy and the use of devices such as electric cars, smart meters, and photovoltaic panels play a major part in this process [110]. This also shows that pursuers of energy projects are aware of climate change risks and strive to mitigate them through various means. One of them is political activism, such as taking part in protest and support movements. Such individuals feel the need to pursue energy justice and to prevent energy poverty as part of their value system [107]. The different approaches to energy citizenship include those which call for going beyond the *homo oeconomicus* model, i.e., beyond using financial incentives to encourage consumer involvement in the energy transition through investment in innovative energy technologies, as this may lead to inequalities and exclusion of poorer citizens. It is, therefore, necessary to transcend individualistic approaches and start treating energy as an ecological resource to be managed via collective decision-making, rather than a commodity. In an energy citizenship model, electricity should not be a problem of individual consumers, but should drive well-being on the level of neighborhoods and districts [111]. In light of the above, energy citizenship should be understood to be renewable energy prosumerism supported by political prosumerism, with the latter laying the groundwork for a new kind of socioeconomic and political order [112].

3.6.4. Energy Poverty

Energy poverty is related to the idea of energy justice in the sense that one is the reverse of the other. The United Kingdom uses a fairly strict definition of energy poverty as a situation where a household is forced to spend more than 10% of its income on maintaining an adequate level of warmth [113]. This refers to the energy costs required to achieve a minimum or standard level of heating to preserve one's health and maintain thermal comfort, while also being able to satisfy basic needs such as adequate lighting, cooking, or refrigeration [114]. This definition is also unofficially used in other countries, but is considered insufficient.

Energy poverty is caused by three factors: high energy costs, low home energy efficiency, and relatively low household income [115–117]. Some have also identified a link between energy poverty and gender, pointing to the underrepresentation of women in the energy sector and the increased prevalence of energy poverty among older women (compared to men of the same age). Accordingly, it has been posited that some issues of energy in relation to gender should be integrated into energy justice. That is why it is a worthy cause for the prosumer movement to gradually eliminate this issue by uplifting the socio-economic conditions to give citizens access to affordable and clean energy [107].

In 2016, energy poverty affected around 4.6 million people in Poland, who make up 1.3 million (12%) of Polish households. Energy poverty has been one of the major contributors to air pollution—low-income residents use coal stoves to heat their homes, especially in rural areas, where most houses were built with large usable areas and low energy efficiency. Of the people affected by energy poverty, 2.5 million (i.e., more than half) were also poor in economic terms. However, the other 2.1 million have experienced energy poverty, but not economic poverty. It follows that energy poverty is not always caused by economic poverty, but may stem from other factors [53].

Energy poverty is strictly linked to the problem of low emission, i.e., releasing the by-products from burning solid, liquid, and gaseous fuels by emitters located at a height of no more than 40 m [118]. A survey encompassing three provinces of southern Poland showed that coal is the most popular fuel for heating buildings and preparing domestic hot water, used by 41% of the respondents. It is also one of the cheapest energy sources. Nevertheless, of the respondents not using heat from the heating network (68% total respondents), 27% admitted to burning waste in heating stoves. This is a concern, as such waste often contains high amounts of damaged building materials containing asbestos and other hazardous substances. Additionally, 30% of the respondents reported being aware that burning low-quality fuels emits toxic gases, highly hazardous to the human body [119]. An analysis of annual household energy costs shows that, taking into account the installations needed to heat the house and prepare domestic hot water, the cheapest solution (compared to hard coal) is to use a ground source heat pump, which has an investment payback period of 15 years. Gas and biomass are slightly less economical options [120].

3.6.5. Energy Democracy

At its core, energy democracy is built around the idea that renewable energy generation is more than just an environmentally-friendly way to supply electricity—the rapid take-up of renewable energy may also end up creating more equitable societies by reshaping wealth distribution and political power [121,122]. Energy democracy is an emerging social movement, aiming to spark a transition from a centralized energy system based on fossil fuels to a model of dispersed and locally produced renewable energy, with a particular focus on cooperative and public ownership of the energy infrastructure [123,124]. In other words, energy democracy leverages the relationship between energy ownership and political, economic, institutional, and cultural foundations of society to redistribute political and economic power. The social change potential of renewable energy lies in three factors: the dispersed nature of renewable energy, which is a catalyst for changes in politics and ownership structures in the economy; the use of steady, perpetual, and free resources such as sunlight, wind, and water; and lastly, the abundance and widespread accessibility of renewable resources, removing the need to compete for them. Energy democracy incorporates three types of social activism: resisting fossil-fuel-dominated energy systems, restructuring energy systems, and reclaiming energy infrastructure [122]. The movement also draws on values such as energy justice, environmentalism, and racial equity. The literature includes three different approaches to energy democracy: as a process driven forward by a popular movement, an outcome of decarbonization, and a goal or ideal to which stakeholders aspire [125]. Energy democracy operationalization (i.e., specific innovatory initiatives intended to put its principles into practice) is pursued along three lines: popular sovereignty, participatory governance, and civic ownership [126]. The social movement strives to destabilize power relations of a fossil-fuel-based energy system and replace them with democratic relations to establish a community-based decision-making authority [127]. It bears emphasizing that, in practice, the main goal of energy democracy is social justice and economic development rather than climate change [128]. The movement strives for the ideal of completely replacing fossil fuels with renewable energy, the prime example of which is the city of Burlington, Vermont—the first US city 100% powered by clean energy [129].

3.7. Macroeconomic Effects of the Energy Prosumer Activities and Digitalization of the Power Industry

3.7.1. Impact of Prosumer Households on Macroeconomic Indicators

The current state of knowledge on the macroeconomic impact of energy prosumer activity is still relatively limited. Nevertheless, the rising number of prosumers should be expected to eventually produce marked changes across the entire economy. The current body of research suggests that household prosumer activity in the energy market may have some effect on the most important macroeconomic indicators, increasing private consumption, GDP, and employment. Prosumer households enjoy higher disposable incomes thanks to their self-production of electricity and the guaranteed remuneration for feed-in. This, in turn, enables them to increase consumption and invest in power generation technologies, both of which stimulate the economy. Prosumer activity also helps curtail carbon dioxide emissions into the atmosphere [130]. Digitalization of the power industry, which is transforming the traditional operating and business models, has had even more of an impact on the economy as a whole. These trends have led to a reshaping of the entire macroeconomic structure and, thus, to the emergence of such systems as the gig economy and the sharing economy.

3.7.2. Gig Economy

The shift towards a decentralized energy system in the United States and the European Union has occurred within the framework of a new market system termed the "gig economy" (characterized by a growing number of temporary jobs). Development of information technology is one of the leading factors driving organizations and enterprises to increasingly employ independent workers for specific tasks [131–136]. This change in the economic order has led to the emergence of new market actors such as energy prosumers, due to the related decentralization of the energy sector necessitated by climate change. This is attributable to fundamental, top-down changes across the entire energy value chain, which gradually push potential, competences, and leverage away from EU institutions, states, and corporations into the hands of prosumers. This shift is accompanied by bottom-up action to empower prosumers and grant them a larger role in the energy transition. This results in energy democratization through the decreased economic power of energy companies (which, until recently, had a monopoly on energy markets) and the higher share of prosumer-generated electricity in the total energy balance [35].

3.7.3. Sharing Economy

The sharing economy is a novel socio-economic trend of peer-to-peer sharing of goods and services via online social media. The sharing economy is closely related to—and sometimes even conflated with—collaborative consumption [137]. Though some forms of collaborative consumption (such as eating meals socially with a group of friends, travelling to visit a loved one, or a family washing its clothes in a single washing machine) have been a subject of study for a long time [138], it is only now that information technology has uplifted collaborative consumption to a completely different level [139]. As one of its underlying principles, this model of consuming and using goods/services calls for expanding traditional property rights and the possession of things by moving away from rigid materialism and popularizing renting or sharing [140,141]. The idea is to counteract the ubiquitous overconsumption of resources driven by short product lifecycles, planned obsolescence, and the consumers' constant search for ever-new products/services. With this in mind, collaborative consumption can be viewed as a potential catalyst of sustainability [142]. Waste can be reduced by embracing sharing, renting, gifting, bartering, swapping, lending, and borrowing. Extensive interaction between different communities, made possible by network technologies, can help avoid unnecessary purchases, find ways to use idle assets, and reuse unwanted possessions [143]. Collaborative consumption is based on the triad of: a platform provider, a peer service provider, and a customer [144]. The platform provider offers matchmaking, making it easier for the customer to procure assets of a peer service provider.

The success of the sharing economy lies in the capacity of digital platforms to generate network effects [137]. Ongoing debates on the sharing economy seem to paint it as a niche of innovation, a force of decentralization and transformation of existing technical and socio-economic structures (regimes). Within this framework, it is defined in its six aspects as [145]: an economic opportunity; a more sustainable form of consumption; a pathway to a decentralized, equitable, and sustainable economy; creating unregulated marketplaces; reinforcing the neoliberal paradigm; and an incoherent field of innovation. The combination of the first two aspects may cause the sharing economy to become dominated by corporate co-option, which would likely complicate the transition to sustainability. This phenomenon is clearly complex and has, therefore, yet to be precisely delineated, but the extensive body of research does point to the following definition [146]:

> *The sharing economy is an IT-facilitated peer-to-peer model for commercial or non-commercial sharing of underutilized goods and service capacity through an intermediary without a transfer of ownership.*

This conception is consolidated and systemic in that it draws on the majority of research to date and covers most aspects of the phenomenon. The sharing economy may be defined as a socioeconomic system supported by digital technology and characterized by five attributes [147]: temporary access, transfer of economic value, platform mediation, expanded consumer role, and crowdsourced supply. For the sharing economy to grow, one-sided users of digital platforms (users who have been exclusively providers or consumers) would have to assume the other role. In other words, the idea is to create as many prosumers (actors who both provide and consume) as possible. Research indicates that one-sided users are driven to become prosumers not only by economic benefits, but also by factors such as trust, gratitude, enjoyment of the activity, and sustainability of collaborative consumption [137,148]. In this light, the sharing economy has much in common with the gig economy and wikinomics. As a prosumer-based phenomenon, its importance for the energy sector cannot be overestimated.

3.8. Methods of Regulating the Energy Sector in a Prosumer Economy

3.8.1. Traditional versus Contemporary Electricity Policy

The evidence indicates that prosumption does not conflict with traditional electricity law norms. One such norm—one of the more crucial ones—is the reliability of electricity service, i.e., maintaining a constant balance between electricity supply and demand while ensuring a stable grid frequency. This merits further exploration, as the renewable energy sources most commonly used by prosumers (such as sunlight or wind) create completely new complications for energy system reliability due to their intermittent nature. The wind does not always blow and the sun does not always shine. A rapid upsurge in the total amount of distributed generation may easily cause an overload of distribution grids [42]. These problems may be alleviated with specific types of distributed resources, such as demand response programs and energy storage, and there are high hopes for combining photovoltaic panels with energy storage systems. Another major norm of a traditional energy policy requires that consumers have access to electricity at reasonable rates while ensuring stable viability utilities—a prerequisite to stable and reliable electricity access. Prosumption may prove beneficial in this regard as well, by helping achieve a better pricing policy, even with the costs of incorporating distributed energy resources into the system and implementing demand-side management. One factor that could keep such costs down would be the reduced demand for new transmission grids, as without the need to transmit energy over long distances, line losses would be reduced [31].

The modern electricity law norms, which emphasize eliminating environmental externalities and boosting industry competition, are highly convergent with prosumption processes [31,42]. Climate change has resulted in the relationship between energy and environmental law being closer now than ever before. Environmental considerations must be increasingly taken into account when designing energy systems. Prosumption mediated by distributed renewable energy resources causes environmental benefits in the form of reduced pollution. Another energy regulatory norm relates to competition. It is assumed that competition provides a major improvement over the old energy market model (which was based on strictly regulated monopolies) by reproducing its benefits without the regulatory inefficiencies. Prosumption based on distributed generation obviously increases market competition by ensuring a diversified supply of electricity. Demand response resources provide the same advantage, as they allow operators to balance energy markets not only by increasing supply, as in the traditional model, but also through contraction of demand.

3.8.2. Economic Stimuli Shaping Prosumption

Measures used to regulate prosumption within the framework of current economic policy include mandates, incentives, environmental policies, and structural reforms [31,42].

1. Mandates are specific renewable power generation targets for municipalities, provinces, or entire countries, often alternatively referred to as renewable portfolio standards. These mandates require utilities operating within a given area to achieve a specified share of renewables in the generated electricity by a certain date. Mandates tend

to support prosumption by incentivizing the utilities covered by the mandate to purchase renewable customer-generated electricity [149].

2. Economic incentives encompass a wide variety of economic stimuli intended to boost prosumption. Examples include tax credits, rebates, or savings designed to reduce the cost of deploying renewables technologies. Many incentives encourage the creation of advanced energy storage systems, such as the installation of behind-the-meter batteries. Pricing programs incentivize capital investment, for example, in net energy metering, to ensure customers are remunerated at a generous rate for the energy sold back to the grid. Another option is the feed-in tariff, which allows homeowners with photovoltaic panels to conclude long-term contracts utilities, guaranteeing a specific rate for the excess energy fed to the grid. The rates usually vary depending on the source of renewable energy, which is done to support selected technologies to promote an economically optimal and sustainable energy mix [150]. Some incentives may be designed to eliminate barriers that discourage prosumption. These include granting prospective prosumers the right to sunlight by building solar fences around protected buildings to ensure they are not shaded by new constructions, obligating utilities to publish distribution grid information, so that individuals are able to see where the best prosumption opportunities are, and finally, ensuring that local governments reduce installation costs.
3. Environmental regulations are a form of indirect incentives to engage in prosumption. They make it less cost-efficient to operate large, centralized fossil fuel power plants, thus encouraging utilities (at least, in theory) to generate electricity from renewables. This results in increased competitiveness of renewable distributed generation, demand response, and energy storage measures. Such policies tend to include greenhouse gas caps and/or carbon dioxide pollution standards imposed on existing coal-fired power plants operating within the given area. Meeting these requirements encourages prosumption by making it easier to involve consumers in distributed generation and demand response programs.
4. Structural reforms mainly relate to the transition from centralized, hub-and-spoke power production systems to a model based on on-site generation and demand-side management (mediated by distributed system platforms and intelligent network platforms, which coordinate the market). Another form of structural reforms is the municipalization of the electricity system—transferring the regulatory responsibility to a new entity, such as a commune, by means of public and localized regulation of the electricity sector. This promotes supply-side democratization, decentralization, and decarbonization of the energy system on the local level, in particular by granting the commune control over its electrical distribution, purchasing, and generation. Such measures may drive replacement of the local investor-owned utility with an electric cooperative or municipal utility, perhaps owing to the common perception that new entities are better for the development of distributed generation and will be able to handle the growing number of solar prosumers. Though municipalization does entail certain costs, it can also help democratize the energy market and empower prosumers to shape energy policy [31].

As a type of economic incentive, subsidies are of great importance for the development of household solar power plants—whether within or outside the grid. As shown by a study conducted in the Czech Republic, public support reduces initial investment costs and, consequently, cuts the payback period down by 3–4 years. This bolsters the economic efficiency of prosumer photovoltaic systems, which in turn translates to encouraging economic indicators such as cash flow, cumulative cash flow, discounted cash flow, net present value, and internal rate of return [151]. According to a case study in Poland, the best economic performance is achieved when the net subsidy value accounts for 19.10% to 27.20% of the total investment costs and when the photovoltaic installation has an installed capacity of 10 kWp [152].

3.8.3. Democratic Experimentalism

Modern-day prosumption is determined by electricity policy that is incredibly complex and falls under the trend of democratic experimentalism, which represents something of a counterpoint to the completely rational approach to policymaking. The experimentalist approach may be warranted, given the inexperience of policy-makers and utilities in regulating renewable energy prosumption, which makes it difficult to effectively design suitable solutions. Polish legislation offers several examples of decision-makers learning from practical experience [153–155]. This mode of thinking can be supported by the incrementalist paradigm, which states that some problems are too complex to predict all the effects of a given policy choice. This issue can be approached from two standpoints. On the one hand, experimentation does seem to be a justified approach—after all, prosumption is based on complicated and rapidly developing technologies. On the other hand, fully leveraging the fruits of the incrementalist approach would require some measure of centralized control over electricity generation and/or coordination of electricity-related efforts. It would also be prudent for the central government to establish a set of objectives for prosumption policy and metrics for measuring the effectiveness (and thus, usefulness) of different policy types [31]. As it is, energy policymaking remains a super wicked problem.

4. Discussion

Thus far, the information about renewable generation prosumers and which energy ecosystems they should operate in is still unreliable and scattered across different sources—so much so that a novel smart knowledge network would be needed to collate the data into one coherent and logical whole (which could have the added benefit of reducing the uncertainty of the collated knowledge and eliminating the current information redundancy). This speaks to the necessity of literature review initiatives to collect dispersed knowledge [78,156] and identify the research hotspots [157] and prospective lines of prosumer energy development such as the Energy Internet [158–162], uses of blockchain technology [68,163,164], or development of innovative energy business model designs incorporating a deep reinforcement learning technique [165].

As it is, formulating a reliable and universal network of knowledge on social policy to prevent environmental degradation worldwide is an extremely challenging and complex proposition—a textbook example of a wicked problem [166,167]. Tackling social policy problems usually ends in failure due to the highly complex nature of the considered issues. Even formulating the issue itself may pose a challenge. The pluralistic society is completely unable to agree on how to define "undisputable public good" or "equity". In addition, there are no reliable criteria for evaluating policies aimed at dealing with social issues—the success or failure of such measures can only be speculated upon. Optimal solutions can only be achieved by applying stringent constraints. The resultant solutions can be neither final nor objective. This is what separates wicked problems from tame problems often encountered in science [168]. Examples of wicked problems include homelessness, social injustice, drug trafficking, natural hazard, and healthcare. Wicked problems can also emerge in socio-technical settings, as exemplified by the problem of energy efficiency [169] and low carbon energy transition [170].

Some issues are further classified as super wicked problems, which include, first and foremost, the problem of global climate change. Super wicked problems have four key characteristics [171]:

1. There is a time limit on finding the solution,
2. Those seeking to solve the problem are also causing it,
3. There is no central authority appointed to find a solution,
4. Certain policies designed to prevent problems are irrational and impede future progress.

This confluence of factors begets a policy-making "tragedy" impervious to traditional analytical methods, preventing action that could mitigate disastrous consequences in the future. It should be possible to overcome this tragedy by applying path-dependent policies designed to impose certain limits on our future collective selves. Sticky interventions in the form of well-chosen trajectories may be a useful tool to achieve this, progressively and incrementally entrenching positive trends across the entire expanding population [171]. Issues of environmental lawmaking are part of what makes climate change a super wicked problem. Environmental law is susceptible to being gradually undermined due to the extent of financial resources that need to be deployed in a short timeframe to achieve goals many decades or even centuries away. To ensure long-term effectiveness, climate change legislation must be designed according to institutional design features which would uncouple its programmatic implementation from powerful political and economic interests mired in short-term thinking. One proposal is to introduce some measure of planned flexibility to environmental law by incorporating asymmetric precommitment strategies. On the one hand, this would complicate changes to legislation; on the other, it would open up ways to introduce certain amendments to deal with other long-term problems, as long as they are in line with greenhouse gas emissions reductions [172].

Several methods have been put forward to tackle wicked problems, including authoritative, competitive, and collaborative strategies [173], as well as an approach based on managed networks [174]. Some make use of issue mapping and visual language [175–177]. While these proposals are interesting and help find solutions to wicked problems, none of them constitute a fundamental breakthrough in social sciences, which only proves that human skill and intuition is very difficult to replace. Visualization of wicked problems can be considered to be a step in the right direction—after all, according to René Thom, the creator of the theory of morphogenesis, the dilemma of all scientific explanation lies in the choice between magic and geometry [178] (p. 5).

5. Conclusions

The survey of the scientific literature on the energy transition shows that it raises the complexity of the interrelated subsystems of the global economy, which include society, economy, legislation, and the environment. At the same time, societies cannot give up on either developing the green energy sector (as it is a remedy for global warming) or striving for sustainable development of the global economy (as this is a condition for the survival of humanity). These two mutually exclusive goals are the quintessence of the present situation in which the whole world has found itself. Thus, the energy transition meets all four conditions of being regarded as a super wicked problem. It is obvious that the time available for finding a solution to the problem is limited, as the climate system can reach the point-of-no-return at any moment, the crossing of which is particularly dangerous as the hazards cannot then be overcome [179]. Some legislative solutions create new problems, such as the contradictions between the short-term and the long-term prospects of the energy policy, the cross-subsidization linked with the transfer of utility's fixed costs between energy prosumers and traditional consumers, or an uncertain experimentalist approach. Moreover, there is no central body to coordinate the energy transition on a global scale. Many local attempts at a concentration of efforts in this regard may be made, such as the European Union's climate policy, but, naturally, their range is limited. There are also plans for solarization of the global energy infrastructure, but this requires thorough changes in policy and outlook on the world for mankind's transition to a new socio-economic system, called solar communism [180,181]. Finally, there are many examples of irrational policies with an adverse impact on the future, as the complexity of the problem makes it difficult to predict all of the consequences of adopting a specific solution.

The situation is made more complicated by the need for the energy transition in prosumer capitalism, which is a relatively new and not fully known economic system. The basic problem, already noted by Toffler, is the externalization of the labor cost linked closely to synergistically double exploitation, extensively discussed by Ritzer. Unpaid human labor results in a transfer of the surplus value from prosumers and consumers to large enterprises and international corporations, thereby boosting their profits. Until now, economic exploitation did not damage the existing economic relations. However, one cannot be certain that it will not happen in the future. If this resulted in disruptions in the energy markets, it would be dangerous for the whole world.

Complexity theory has a large cognitive potential, which can be used in studying organizations and organizational change [182,183]. There is no doubt that the energy transition creates a highly complicated system of interdependencies between society, the economy, legislation, and the environment. It is a huge challenge to organization science. According to the general systems theory, the development of such complex structures is governed by certain laws. The number of states possible in a simple system, comprising few components and interdependencies between them, can be much smaller than the number of challenges originating in the environment. Its adaptability is then low, and the system's increase in complexity is a positive process. It must be enriched with new elements and proper connections between them. However, development can have not only lower but also upper limits. If a system has many components which are interrelated in many ways, an increase in its complexity above a certain level may reduce its adaptability. Kauffman called it the complexity catastrophe [184] (pp. 52–54), [185–187]. It can occur in both biological and socio-economic systems, and the complexity can be reduced to a safe level in both [188,189]. Complexity catastrophe is a well-known phenomenon in organization science, where it has well-established applications [190–194]. Development of the complexity reduction methods in this science can be useful in raising the effectiveness of the socio-economic policy by preventing the energy transition from becoming a super wicked problem.

Making use of the accomplishments of the general systems theory to reduce the complexity of the issues of the energy transition can be supported by a related method called change management [195–199]. This is usually understood to denote a systematic approach, within which organizational strategies, structures, procedures, and technologies aimed at adapting the organization to a change in the external conditions and the business environment are defined, developed, and implemented. Many methods of an organization adapting to changes have been developed, for example, the three-stage change model by Kurt Lewin, which includes unfreezing, moving, and freezing group standards [200], or a more developed model by John Kotter, which comprises eight steps: establishing a sense of urgency, creating the guiding coalition, developing a vision and strategy, communicating the change vision, empowering employees for broad-based action, generating short-term wins, consolidating gains and producing more change, and anchoring new approaches in the culture [201].

In recent years, both system control methods, avoiding or alleviating complexity catastrophes, based on complexity science and change management based on management and organization science were combined to make a new approach called complexity management [202–209]. The main concepts in change and complexity management are usually microeconomic, which may be necessary and useful for exemplification, as this is confirmed by numerous experiments. However, when it comes to the energy transition, change management and complexity management must be redefined to make those approaches global in nature. However, this may not be enough to solve the major issues related to energy transition. All attempts at alleviating complexity catastrophes by developing and implementing proper methods of change management and complexity management directed towards reducing the energy transition complexity may be doomed to failure. This is caused by the lack of a central organization in the form of a global super-organization responsible for solving the problem on a global scale. Since the problem is global, its solution must also be global.

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