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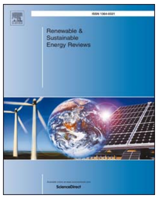

Distributed energy systems on a neighborhood scale: Reviewing drivers of and barriers to social acceptance

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ABSTRACT

Distributed energy systems (DESs) on a local scale constitute a promising niche to leverage the provision of renewable energy. DESs such as micro-cogeneration and multi-energy hubs integrate renewable energy sources, small-scale combined heat/power production, various energy storage methods, and active demand-side management. Research on adopting these systems within existing neighborhood contexts remains scarce, however, particularly on the role of local actors such as local energy utilities, ownership, and the spatial scale of implementation for accelerating the adoption of DESs. In this study, we conducted a systematic review of the relevant scientific literature on the adoption and social acceptance of DESs, followed by a series of semi-structured interviews with representatives of DES pilot implementations. Our findings indicate that local co-ownership and awareness of local benefits tend to improve the acceptance of distributed energy infrastructures. The study found that established energy actors such as energy utilities and grid operators currently test DESs on a local scale in terms of the systems' technical and financial feasibilities. The study also identified major regulatory and structural barriers to DES market adoption that must be overcome to accelerate the current rate of niche development; the study thus contributes to developing DES adoption strategies. We provide future research trajectories that would address the role of spatial proximity and deployment models to attain a more dynamic understanding of the social acceptance of new energy technologies.

1. Introduction

Numerous countries now have the significant deployment of low-carbon-energy technologies on their policy agendas. Countries such as Great Britain, India, Germany, and Switzerland [1–4] have all defined transformation targets for their existing energy regimes that are driven by growing concerns about climate change and updated risk evaluations of nuclear power following Japan's 2011 Fukushima nuclear accident [5–7]. In combination with improvements to energy efficiency, the rapid increase in renewable energy supply is widely considered to be a transitional pathway to achieving more sustainable energy systems. The use of large amounts of fluctuating renewable energy, however, requires spatial and temporal flexibility in terms of power generation, short- and long-term energy-storage capacities, efficient conversion technologies, and reliable grid architectures [8,9].

One way to deploy this type of embedded renewable energy production regime is to use distributed energy systems (DESs) such as micro-cogeneration and local energy hubs. These DESs integrate renewable sources such as photovoltaics (PV) and wind, enable small-scale combined heat and power (CHP) production, use various energy-storage methods, and implement active demand-side management of numerous small and geographically scattered generation sites [10]. These systems offer several advantages, including balancing excess power production (such as from PV or wind) with energy storage and demand-side management; efficiently co-generating electricity and heat, thus contributing to the reduction of CO2 emissions; and increasing cost-effectiveness through an optimal combination of complementary production and demand [10,11]. But because DESs are complex systems that enable the integration of several interconnected technologies for the exchange of electric, thermal, and chemical energy (as well as operating information), the design, development, and adoption of such systems in specific contexts all present a variety of challenges. These challenges range from the selection of an optimal set of technological components to the settling of potential conflicts among the different stakeholders involved in the implementation.

One focal area for the study of transitions toward the adoption of new energy technologies is often these technologies' acceptance by different societal actors. For this reason, a large body of literature has

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discussed the acceptance of single renewable energy technologies [e.g., [12,13]], while scientific studies that specifically analyze the acceptance of DESs that combine renewable energy generation, energy conversion, and energy storage in local distributed structures remain scarce.

The acceptance of new energy technologies is a broad concept that several different scientific disciplines have examined, although to date, a coherent overview of this knowledge across different scientific disciplines is nonexistent. In addition, DES implementations that integrate renewable energy generation, conversion, and storage are currently increasing in number yet still remain niche developments within centralized energy regimes, for example in the United States [14], Great Britain [15], Germany [16], and Switzerland [17]. Their diffusion process is thus still in its infancy. Little to no empirical work has been undertaken to examine how these systems might further evolve from their technological niches. A systematic review of the scientific literature on the acceptance of DESs across disciplines and an examination of initial empirical insights from pilot applications will thus help to identify barriers to and drivers for the adoption of DESs.

1.1. Conceptual background of distributed energy systems

DESs may be defined as units that convert and store energy and are located close to energy consumers [18]. A DES application may comprise renewable sources such as PV, solar thermal collectors, hybrid collectors, or wind turbines for local power generation that are combined with various local- and regional-scale distribution technologies. Such technologies may consist of smart grids, microgrids, or district heating/cooling networks as well as local capabilities for power storage and conversion, including batteries and power-to-gas conversion, among other technologies [10]. Ackermann et al. [19] argue that DESs may differ according to “the purpose, the location, the power scale, the power delivery, the technology, the environmental impact, the mode of operation, the ownership, and the penetration of distributed generation” (p. 196). A variety of different types of DESs are thus currently in use, including energy hubs [10], micro-cogeneration systems [20,21], and distributed generation within smart grids [6]. Among these different types of DESs, an energy hub may be thought of, as Parisio states, a “decentralized multi-generation energy system” comprising “functional units where multiple energy carriers are converted, stored, and dissipated” [22, p. 98]. An energy hub may range from an individual building to a city neighborhood, a city quarter, or an entire city [10].

Cogeneration or CHP production is, as Pehnt states, “the process of producing both electricity and usable thermal energy at high efficiency and near the point of use” [21, p. 1]. Micro-cogeneration refers to particular small-scale CHP units. Whereas the European Union defines a micro-cogeneration system as one with a maximum capacity below 50 kW_{el} [23], Pehnt [21] prefers to restrict the definition to single units below 15 kW_{el}. Recent studies have extended the approach of cogeneration and micro-cogeneration to the concept of polygeneration, which Rong defines as “the simultaneous generation of two or more energy products in a single integrated process” [24]. This means that polygeneration involves CHP production as the basic form but may also occur as the trigeneration of heat, cooling, and power (known as CHCP), particularly in small-scale contexts.

Distributed generation in smart grids focuses on specific characteristics of the grid technology. Smart grids enable flexibility in electricity networks and are meant to facilitate distributed generation, preferably from renewable sources [6]. Smart-grid approaches may be applied on different spatial scales. For example, small grid units or microgrids might operate either independently or in conjunction with the regular transmission grid to meet the demands of different energy consumers [25].

Whether the different types of DESs differ in terms of their social acceptance is currently unknown. According to Fischer [26], micro-cogeneration “blurs the boundaries between energy consumers and producers” (p. 118). A broad range of individual and corporate users of cogeneration currently exists; Fischer argues that these users’ motivations to adopt cogeneration technology follow “different mixtures of producer and consumer logic” [26]. Accordingly, heterogeneous patterns of technology acceptance may occur.

1.2. Acceptance of energy technologies

The implementation of energy technologies is not simply a function of technological optimization and economic feasibility; the development is also considerably determined by social-acceptance issues. Following the arguments of Wüstenhagen et al. [12], the concept of acceptance is key to the question of beneficial or hindering conditions for the implementation of new energy technologies. The acceptance of energy technologies is a broad concept that has been widely applied across different scientific disciplines. Several definitions of the concept have been proposed because of this diversity of research perspectives. Energy-technologies acceptance may be defined as an affirmative reply or a positive attitude toward a technology or measure that is likely to lead to supporting behavior for the respective technology if necessary or requested. The social acceptance of energy technologies can also be described as the counteracting of resistance, whereas acceptance that solely consists of an attitude lacking in supportive behavior may be described as “tolerance” or passive acceptance [7,27].

Previous research has focused on (a) the socioeconomic dimensions of acceptance as well as the (b) spatial and temporal aspects and (c) psychological factors associated with acceptance. As Devine-Wright et al. have noted, the study of the social acceptance of energy technologies “has blossomed over the last decade” [27; p. 27]. Researchers have focused on acceptance issues related to renewable energy technologies in general [7,12,13,28] or on the acceptance of individual renewable technologies. An abundance of studies have examined the acceptance of wind power [e.g., [29,30–32]], whereas fewer studies have been published on solar [32,33], geothermal [34,35], and hydro [36,37] power. In addition, few studies have investigated the acceptance of energy-storage technologies [27,38] and other energy infrastructures such as high-voltage power lines [39] or smart metering technologies [40]. Studies that consider acceptance issues related to combined systems that include energy generation, conversion, and storage in locally distributed structures such as energy hubs and smart grids remain scarce. Research on smart-grid applications, for example, has tended to entirely neglect these social determinants [6,27]. To date, research on energy hubs has failed to examine questions of social acceptance.

Wüstenhagen et al. [12] suggest three dimensions of social acceptance of renewable energy implementation —sociopolitical acceptance, community acceptance, and market acceptance—each corresponding to a different domain of the agents involved. In their recent study, Devine-Wright et al. [27] refer to these three dimensions and conclude that social-acceptance studies rarely build on interdisciplinary approaches. In addition, the authors report that acceptance studies that combine “market, socio-political & community aspects are scarce” (p. 27). The authors propose the idea that key actors’ belief systems and social representations play important roles in fostering the acceptance of novel energy technologies; the authors exemplify their framework of analysis using renewable energy storage technologies. In addition, the authors point to the role of scale (between the local and national levels, for example) and how specific actors mediate change processes in acceptance between scales: for example, a generally positive attitude toward renewable energy technologies versus local community resistance to concrete and proximate installations (i.e., NIMBYism).

When implementing a DES on a neighborhood scale, spatial proximity and people's place-related attitudes should be considered. In addition, the spatial scale of implementation (i.e., the extent of implementation of the respective technologies) has often been described as an important factor associated with the acceptance of energy technologies. In the context of social acceptance, Devine-Wright [13] classifies three scales of implementation of renewable energy technologies: