Energy Policy 122 (2018) 214–228

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Independence without control: Autarky outperforms autonomy benefits in the adoption of private energy storage systems

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ARTICLE INFO

Keywords:
Decentralized energy storage systems
Technology adoption
Peer-to-peer energy trading
Autonomy
Energy autarky
Purchase motives

ABSTRACT

Decentralized energy storage systems (ESS) are a promising means to more effectively match the supply and demand of fluctuating renewable energies. In most countries, however, ESS market share is small and whether or not the technology will attain a critical market share is subject to homeowners' investment decisions. For policy and industry alike, it is of particular interest to identify factors that drive ESS adoption. Empirically addressing this question, we hypothesized that the factors *autarky* and *autonomy* aspirations crucially determine ESS adoption decisions. In two studies (N_{total} = 489), sketching future decentralized energy scenarios, we found evidence for the importance of both factors for homeowners' evaluations of the technology. However, only autarky significantly affected homeowners' willingness to pay extra for ESS, in that homeowners invested more in the technology when autarky was higher (Study 1) or autarky benefits were emphasized (Study 2). In accordance with concepts aspiring to optimize energy flow on the low-voltage grid level (e.g. Smart Neighborhoods), we additionally examined the influence of autarky and autonomy aspirations on homeowners' willingness to exchange self-generated energy within a local energy network. Results showed that emphasis on autarky increased the subjective value of self-generated energy, decreasing the likelihood of peer-to-peer energy trading.

1. Introduction

Around the globe, energy from renewable sources has become an important element of energy supply. The worldwide uptake of renewable energies in recent years constitutes a promising pathway toward cleaner energy provision. However, in contrast to conventional fossil-based energy generation, renewable energy sources such as wind and photovoltaics (PV) are accompanied by a crucial shortcoming: Fluctuation depending on weather conditions, complicating the matching of energy supply and demand. The volatile generation of renewable energy increases the risk of grid instabilities and raises the need for cost-intensive power plants that feed-in energy in times of low renewable energy supply (Sims et al., 2011). Moreover, specific weather conditions can lead to a surplus of renewable energy at peak times, potentially resulting in negative energy prices (Fanone et al., 2013). A promising solution is to store energy from renewable sources in times of surplus and to feed it back in times of demand. Storing electricity surpluses may balance generation and use of energy, thus stabilizing the electricity system as a whole (Li and Danzer, 2014). While the installation of large-scale storage systems is often accompanied by substantial technological, geographical, and financial drawbacks (Poullikkas, 2013), effective overall energy storage capacities could be yielded by comprehensive adoption of small-scale decentralized energy storage systems (ESS) such as solar batteries in private homes (Denholm et al., 2010). However, although the installation of PV modules has steadily increased over the last decades (IEA, 2016), adoption rates of decentralized ESS are still low, despite substantial research and marketing efforts from industry as well as governmental subsidies in various countries. As a result, decentralized ESS are still a niche product (Schill et al., 2017; Schmela, 2017).

In light of the pertinence of small-scale ESS as a decisive factor for a successful transition of the energy system (Weniger et al., 2015; Kairies et al., 2016; Synwoldt, 2016), it is pivotal to gain a deeper understanding of the key factors that determine their adoption. Although a large body of research has examined the technological and financial aspects of ESS (Abdon et al., 2017; Denholm et al., 2010; Fuchs and

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https://doi.org/10.1016/j.enpol.2018.07.028
Received 13 April 2018; Received in revised form 13 July 2018; Accepted 14 July 2018

Demiray, 2017; Hall and Bain, 2008; Li and Danzer, 2014), only little research has yet investigated factors influencing consumers' investment decisions. Knowledge about such motivational factors is necessary to develop strategies to promote ESS on the industry as well as on the policy level. Serving as a starting point of a more comprehensive investigation of the factors determining the adoption of ESS, recent research has applied quantitative and qualitative research methods to identify motivational factors relevant for investment decisions in the realm of decentralized renewable energy system (Ecker et al., 2017, for further research see Römer et al., 2012, 2015). This research emphasized the relevance of individual autarky and autonomy benefits for investment decisions. However, empirical insights about the strength of the factors' influences on investment decisions as well as their underlying motives (e.g., need for security, control) are still scarce. In order to address this gap, we examined homeowners' willingness to pay extra for ESS in diverse potential future energy scenarios (cf. Studies 1–2) and experimentally varied the individual autarky and autonomy attained in the scenarios.

In addition to investments in technology, decentralized energy concepts (i.e., smart neighborhood, Rosen and Madlener, 2014; López et al., 2015; von Wirth et al., 2017, or community level, Parra et al., 2017) require participation of private stakeholders. In future decentralized energy scenarios, owning a PV system with an electricity storage unit puts homeowners in the position to decide whether they want to store home-generated energy or sell it, for instance, to their neighbors (or their electricity provider). Such peer-to-peer transfer or trade of energy appears highly beneficial as it optimizes energy distribution already on the level of low-voltage grids, which are responsible for end customer supply. However, it requires participation and cooperation among private stakeholders (Parra et al., 2017; Rogers et al., 2008; Walker et al., 2010; Warren and McFadyen, 2010). Little is known about the extent to which homeowners would be willing to participate in such peer-to-peer energy trading and under which conditions they would be willing to sell or buy home-generated energy within a social energy network. In the present research, we simulated future energy exchange scenarios in which participants were asked to trade home-generated energy with their neighbors (cf. Study 2) in order to gain more insights into homeowners' decision processes under these conditions.

2. Adoption of energy storage technology

In contrast to traditional centralized energy systems, decentralized generation of energy requires investments of local residents and makes active participation and collaboration more likely (López et al., 2015; von Wirth et al., 2017). Especially in the case of energy production and storage via PV modules and battery systems, respectively, homeowners' motivation is of crucial importance (Gährs et al., 2015; Oberst and Madlener, 2014). Theories of human motivation posit that actions and decisions are rooted in the pursuit of achieving defined outcomes or goals (Ajzen, 1985; Deci and Ryan, 1985; Edwards, 1954; Gollwitzer and Bargh, 1996; Lindenberg and Steg, 2007; Vroom, 1964). According to rational choice models, such as the Subjective-Expected-Utility Theory (Edwards, 1954) or the Theory of Planned Behavior (Ajzen, 1985, 1991), decision-making is based on individual cost-benefit analyses. Accordingly, individuals opt for the alternative which maximizes their subjective expected benefits. Previous research in the energy domain has transferred these theoretical considerations to purchase decisions in the realm of decentralized ESS (Korcaj et al., 2015; Römer et al., 2015). In line with theories on expected utility, these studies found that the expected personal financial benefit of residential PV systems was a core determinant of homeowners' purchase intentions (Balcombe et al., 2013; Dóci and Vasileiadou, 2015; Korcaj et al., 2015). However, previous research has also shown that purchase determinants encompass non-financial aspects such as environmental, status, and social benefits (see also: Ecker et al., 2017; Römer et al., 2012, 2015). Of particular relevance for the adoption of ESS, it has been further indicated that the aspiration of energy autarky (Brosig and Waffenschmidt, 2016; Ecker et al., 2017; Engelken et al., 2016; Korcaj et al., 2015; Leenheer et al., 2011; Müller et al., 2011; Römer et al., 2015) as well as supply security (Balcombe et al., 2013; Rae and Bradley, 2012; Römer et al., 2015) are important drivers of renewable energy system adoption.

Theories on human motivation emphasize that, in addition to *what* is achieved (i.e., a certain goal/outcome), a core motivational aspect is *how* a given outcome is achieved (regulatory processes) (Gollwitzer and Bargh, 1996). Self-Determination Theory (Deci and Ryan, 2000; Ryan et al., 1996) differentiates between the content of goals and the regulatory processes through which these goals are pursued. During the execution of an action, experiencing high levels of autonomy, competence or social relatedness lead to a strong motivation to achieve set goals (Deci and Ryan, 2000; Ryan et al., 1996). Transferring these notions to purchase decision-making processes, individuals should be more likely to opt for an option that (1) enables them to achieve their desired outcomes as well as (2) provides them the freedom to achieve these outcomes in a self-determined, autonomous way.

Indeed, in accordance with previous basic and applied research, the few studies investigating technology adoption with specific focus on ESS point to (1) independence of supply (goal: *autarky*) as well as (2) the ability to self-determine one's energy provision (regulatory process: *autonomy*) as the key drivers of ESS adoption (Ecker et al., 2017; Römer et al., 2012, 2015). With the present research, we advance knowledge about the relevance of the two determinants autarky and autonomy in the realm of ESS investment decisions. Whereas previous research on energy storage systems indicated that the two components have an impact on adoption, we sought to extend this research by comparing the strength of both factors' influences on investment decisions as well as to advance knowledge about their underlying motives.

2.1. Peer-to-peer exchange of energy

In addition to investment in technology, peer-to-peer (or cooperative) exchange of energy is likely to become a pertinent aspect of decentralized energy scenarios (Miceli, 2013; Rosen and Madlener, 2014). Units of distributed generation technologies and storage facilities can be linked via modern information technology, connecting neighborhoods and local communities in real-time, allowing to exchange energy within a given network (Kakran and Chanana, 2018; López et al., 2015; Wolsink, 2012; von Wirth et al., 2017). These conditions redefine the role of the individual private actor within the network who becomes energy producer and consumer at the same time (Gährs et al., 2015; Oberst and Madlener, 2014). To optimize energy demand and supply, it is desirable that actors cooperate and exchange energy within the network (Kakran and Chanana, 2018; Rosen and Madlener, 2014; Tuballa and Abundo, 2016). Research, using a game-