Journal of Cleaner Production 128 (2016) 190–200

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Developing mutual success factors and their application to swarm electrification: microgrids with 100 % renewable energies in the Global South and Germany

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ARTICLE INFO

Article history:
Received 1 December 2014
Received in revised form
26 February 2016
Accepted 9 March 2016
Available online 7 April 2016

Keywords:
Energy access in the Global South
German energy transition
100 % renewable energy communities
Microgrids
Success factors
Swarm electrification

ABSTRACT

In the context of climate change mitigation and sustainable energy infrastructure development, this paper focuses on the successful implementation of microgrids supplied by renewable energies in very diverse environments. Taking into account the challenges of reaching economies of scale, this paper is targeted at identifying success factors for microgrid implementation. The success factors are derived from case study analyses of microgrids implemented in the Global South and in communities of Germany. The goal of the research is to develop a mutual understanding of common values and so support future developments. The analysis covers the categories of ownership and participation; technology and system design; and policy and financing. The results show that microgrids in the Global South and renewable-energy-based communities in Germany share a number of success factors. The results demonstrate that a high share of ownership by users and the flexibility to expand the microgrid with user needs are particularly promising features. To verify the application of the identified success factors, the latter are applied to analyze the microgrid concept of "swarm electrification". The analysis concludes that the concept of swarm electrification is consistent with the success factors, making it a high-potential approach for renewable-energy-based electrification.

1. Introduction and research question

Globally, more than 1.1 billion people are without access to electricity from the grid (SE4ALL, 2015). These people lack the resources to access modern energy services that are "affordable, clean, reliable and safe" (Legros et al., 2009). Instead, they pay high specific costs for substitute solutions that are mostly based on fossil fuel. More than half of the global off-grid households pay over USD 5 per month on lighting and phone charging services, totaling on a global scale to USD 19 billion per year (IFC, 2012). The extension of the main grid to the affected areas is often accompanied by delays and low degrees of transparency in the centralized decision and planning processes (IFC, 2012).

Due to the unsatisfactory situation of missing access to electric energy, a universal plan – the Global Goals for Sustainable Development (UN, 2015) – puts forth this key statement: "By 2030, ensure universal access to affordable, reliable and modern energy services". In particular, the increase of the share of renewable energy and increased efforts in energy efficiency are among the objectives (United Nations Foundation, 2012; UN, 2015). These targets are also reflected in the Sustainable Energy for All (SE4ALL) initiative, which considers the implementation of microgrids as a high impact opportunity in the Global Action Agenda: "Develop and

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http://dx.doi.org/10.1016/j.jclepro.2016.03.080
0959-6526/

implement small-scale renewable energy and smart grid solutions" (Sustainable Energy For All, 2012). In line with these goals, more than 43 percent of electricity capacity investments are in the renewable energy sector, excluding large hydro power. This accounts for a global turnover of USD 244 billion (McCrone et al., 2014; REN21, 2015).

Germany used to be at the top of the list of investment in renewable energies. This, however, has drastically changed in recent years. As of 2014, the countries with the largest generation capacity are China and the U.S. Also, there is a close to equal investment spread between Global North and South. Developing countries receive 48% of the total worldwide investments for PV and wind-power. In Bangladesh alone, more than 4 million solar home systems (SHS) with a system size of less than 100 Wp were installed by October 2015 (IDCOL, 2015).

Germany, however, remains a leader in renewable energy innovation. More than 100 communities and regions in Germany have committed themselves to target 100 percent renewable energy supply. These so-called "100%-RE communities" are still connected to the main electricity grid, but have received credit for their endeavor to achieve a high degree of energy autonomy through the usage of renewable energies. Especially in rural areas, some communities have in fact succeeded to become "net energy neutral" (Rae and Bradley, 2012, p.6500), as they generate more electricity than they consume throughout the year. However, they cannot be considered "stand-alone" microgrids, as they are not able to meet the instantaneous power demands of the community in certain time periods of the year. Nonetheless, some of these communities have implemented and operate their own energy supply system based on various renewable sources.

Within this paper, the authors analyze how the dual ambitions of increasing energy autonomy in developed areas and increasing access to energy in off-grid areas can benefit from each other by exchanging experience. A detailed analysis of different cases examines how the 100%-RE communities in Germany and microgrid projects in the Global South share common values. Unlike Marquardt et al. (in press) this paper takes a bi-directional learning perspective. Hence, it also aims at answering the question of how renewable energy powered communities in Germany can learn from cases in the Global South to reach higher levels of energy autonomy.

2. Methods and structure

Different cases to provide insight into selected implementation cases in Germany and in the Global South are analyzed. The analysis across the different cases is performed by utilizing methods of meta-study and thematic synthesis (Barnett-Page and Thomas, 2009). As described by Barnett-Page & Thomas, thematic synthesis relies on three main stages: stage one and two include a review and a descriptive synthesis, whereas stage three refers to the analytical synthesis. At the cross-case level, similarities and differences across the cases are analyzed (Hoon, 2013).

Cases are selected according to their ability to deliver insights into one of the three categories:

1) Ownership and participation,
2) technology and system design, and
3) policy and financing.

Cases are not excluded when information on aspects is missing or not available, as long as their value as an indicative reference is strong. Sources for case studies include literature review, also integrating gray literature such as project reports where needed, as well as expert interviews and site visits.

Following the thematic synthesis structure, the paper is structured into two main sections. In the first section, chapters three and four are descriptive, analyzing cases and papers concerning microgrids in the Global South (Chapter 3) and 100%-RE communities in Germany (Chapter 4); the second section (Chapter 5) gives the cross-study analysis for mutual global learning opportunities and applies the results on Swarm Electrification; in the last chapter, overall conclusions and recommendations are given.

3. Microgrids in the Global South

Examples of technologies introduced in the Global South through market-based approaches range from very small systems which power a single light bulb, to large systems for entire towns (IFC, 2012). Among the household-based approaches two of the examples are solar lanterns and solar home systems (SHS) that can provide light and electricity for fans, mobile phones chargers and small entertainment devices. Systems with a higher number of users are community-scale microgrids. These microgrids are capable of providing sufficient power for basic productive use. A framework, currently under development by SE4ALL and World Bank's Energy Sector Management Assistance Program (ESMAP), differentiates the degree of energy access by different tiers, i.e. level of access, according to quality, reliability and other criteria (ESMAP, 2015). The most basic tier which allows for productive use of energy with small machines is rated at a power supply of 200 W or more (ESMAP, 2015). Microgrids that meet this criterion may be based on renewable energy technologies, diesel generators, or a combination of the two (hybrid) and often include storage technology as well (ARE, 2011; Chowdhury et al., 2015).

This chapter is divided into four sub-chapters, separating the cases with a focus on the general aspects of technology and organization (A), the policy and financial framework of microgrids and stakeholder analysis (B), and recent innovative approaches (C). The chapter concludes with lessons learned from the selected cases.

3.1. A. Microgrid designs in the Global South

The microgrid grid concept has been discussed in the literature as a promising technology for reliable electricity supply with renewable energies (Strunz et al., 2014; Hatziargyriou et al., 2007). This holds true in particular for "places currently poorly served by the traditional power system" (Hatziargyriou et al., 2007, p.94). However, location and economic context have a strong influence on the economic viability of a microgrid project (Chaurey and Kandpal, 2010). Moreover, the prediction of load development is a general challenge in the design of off-grid solutions. A case study of SHS in Zambia showed that energy demand in the household increased with time, leading to over-stress in the systems (Gustavsson, 2007). The socio-economic effects of access to electricity are not limited to SHS, but also apply to community-scale systems, as shown by Kirubi et al. (2009) for microgrids in Kenya. Again, growth in usage is an important factor. A study in India showed that "people gradually started to look for more electricity" (Ulsrud et al., 2011, p.298). These factors are important when looking at the organizational aspects as overload can be interpreted as on overuse of a common good. Both SHS as well as microgrids usually have limitations in terms of upgrades when load patterns change. The increase in demand leads to a mismatch between demand and supply. A microgrid example from China, for instance, shows a reduction in service hours by more than 60% due to over-demand (Shyu, 2013). Decentralized electrification development paths must give incentives to not only simulate growth in demand, but also in generation and storage capacity, as a close match of demand and supply is necessary (ARE, 2011).

The necessity for accurate sizing can be seen in the example of the Sandwip Island Microgrid in Bangladesh (Khan et al., 2015). This 100 kWp photovoltaics (PV), 40 kV A diesel hybrid microgrid was set up in 2010, after an extensive planning and surveying period, involving Bangladeshi and German technical expertise and financing from Bangladeshi and German financial institutions. After three years of operation, households consumed 40% of the electricity, 53% was used by small and medium enterprises. The remaining electricity was used by local institutions as for example schools (Khan et al., 2015). The users connected to the system over an extended period of time, saturating after about three years of operation (c.f. Fig. 1).

For the Sandwip Island case, an initial survey was undertaken in 2008, only including small and large enterprises, indicating a wide coverage with local diesel generators that would run for about three to 4 h per day. Users used to pay between 0.56 USD/kWh and 0.96 USD/kWh for the supply from these local diesel generators. The tariff now applied in the supply by the solar-diesel hybrid microgrid is set at 0.40 USD/kWh, which is not sufficient to recover the capital costs. Khan et al. (2015) underline the importance of demand side management, introducing a shift to energy efficient light bulbs for example. The users of this microgrid have no direct ownership. However, they participated in the financing, as they had to pay an initial connection fee.

The role of bottom-up initiatives can be illustrated with the Sandwip case: Initially, the grid was only operated from 10 am until 11 pm. This made many customers decide to keep their previously acquired solar home system in parallel to their connection to the microgrid to be able to power basic appliances independently at night (see Fig. 2 and Fig. 3 (right)). In addition, some households sought to be connected, but were not allowed to by the operator. These households found an innovative approach: they connected themselves to an already connected neighbor. These so-called "side-connections" were tolerated by the operator, as the consumption was paid for through the grid-meter of the officially connected household (Kirchhoff, 2013).

The power distribution infrastructure amounts to one of the large cost factors in microgrids, accounting for up to 20% of the capital costs (Frearson & Tuckwell, 2013). Against that background, it is interesting that in a microgrid case in Tsumkwe, Namibia, technical planners included two parallel distribution networks (see Fig. 3): one for critical loads (at a capacity of 12 kW) and one for non-critical loads (at a capacity of 80 kW), so that the latter can be switched off easily in the case of low supply. Another important aspect can be observed here: although more than 100 km away from the national grid, the 11 kV distribution line is designed according to Namibian grid standards. It is therefore ready for grid-connection. However, this upward compatibility also comes along with higher investment and additional service costs, as heavy pole-mounted transformers require a service truck to reach them (Kirchhoff, 2013).

Authors of a case study for microgrids in the state of Maharashtra, India, emphasized the benefit of following high standards in

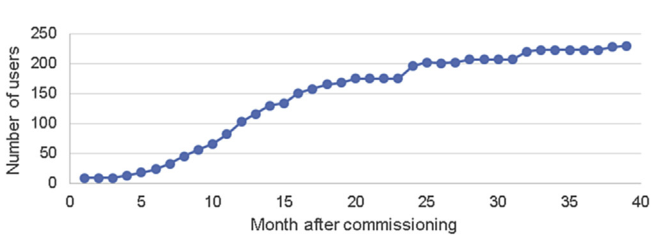

Fig. 1. Number of users of Sandwip Island Microgrid have increased slowly, Source (Khan et al., 2015), own representation.

Fig. 2. Parallel energy access technologies are used on Sandwip Island: Solar Home Systems and Microgrid connection. Source (Kirchhoff, 2013).

wiring and to withstand "the ease of installation that comes from simply stringing wires over trees" (Chandran-Wadia et al., 2015, p.57). For the analyzed microgrid, different mechanisms of load management worked well. The application of reasonable, cost-recovering tariff is of importance, as this "creates a sense of ownership of the assets" (Chandran-Wadia et al., 2015, p.59). Chandran-Wadia et al. (2015) argue that many regulatory bodies in India perceive microgrids as a "stop-gap" technology, more a temporary solution rather than a final solution. However, they also give credit to the involvement of state agencies in their support to bring microgrids to scale in India.

3.2. B. The economics of microgrids — overselling a promising business case

Among donors, investors and the solar industry, the awareness for microgrids powered partly or entirely by renewable energies has risen significantly over the last five years. Either in the form of greenfield projects for off-grid villages or as retrofits of existing diesel microgrids, they have the potential to provide local load sharing and power for productive use at affordable cost. At the same time, they are environmentally benign.

Since around 2011, increasing donor activities and related financial engineering have been discussed or initiated, all looking for a pipeline of investment-grade transactions. In its recent study, Craine et al. (2014) predict a significantly rising market share for microgrids in the overall off-grid sector, as shown in Fig. 4, of about 20%–40% of the total value sold in the off-grid sector.

However, as outlined in Reiche et al. (2015), the business case for microgrids powered by renewable energy systems is a challenging one. Therefore, solid success stories that may be scaled up and increase confidence of equity and debt investors are not easy to find. Many microgrid projects will fail to deliver, not only because they are based on unrealistic levelised cost of electricity (LCOE) expectations and a lack of suitable business models. Also, the skill set, business practices, and experience needed to succeed as an IPP (independent power producer) is often missing. As Reiche et al. (2015) conclude: "This is worrisome because the fundamentals of RE microgrids are perfectly sound" (Reiche et al., 2015, p.3).

Multiple stakeholders are involved in the regulatory and legal processes, finance, building, and operation of microgrids. Balancing, moderating, and mitigating conflicts of power and interest in this multi-stakeholder game are crucial for the successful implementation of microgrids. The major agents on the

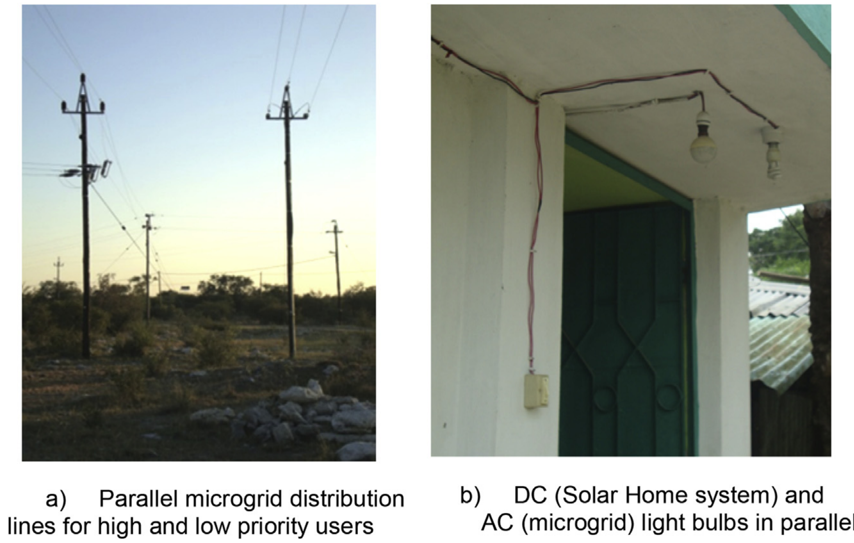

Fig. 3. Parallel infrastructures used in distribution and local wiring. Source (Kirchhoff, 2013).

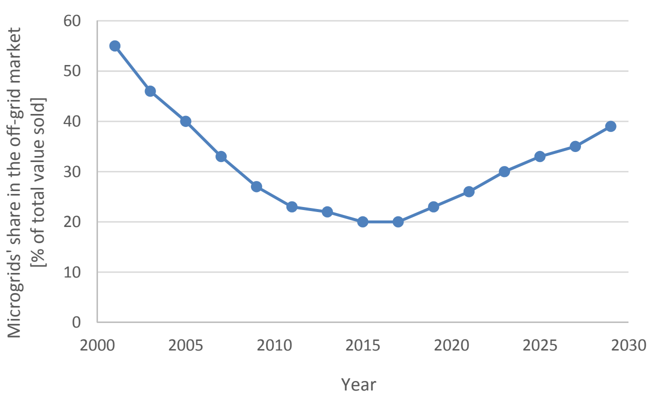

Fig. 4. Microgrids are expected to reach higher market shares in the off-grid sector. Source (Craine et al., 2014), own representation.

international, domestic, and local level and their impact on those processes are outlined below, focusing on:

- International stakeholders,
- the International Renewable Energy Agency (IRENA),
- international development agencies,
- international development banks,
- national governments and national utilities,
- private companies and
- village communities.

International stakeholders are UN agencies and international donor agencies. Among a wide range of activities, carbon financing is facilitated by the UN: Financial resources channeled through the Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change (UNFCCC) may be acquired by microgrid developers.

IRENA, the multinational government agency dedicated to the promotion of renewable energies, pursues a credit -based strategy. In 2014, the organization awarded a USD 5 million low-cost loan to the government of Mauritania, where just 1% of rural communities are electrified.

International Development Cooperation Agencies such as the United States Agency for International Development (USAID), the Japan International Cooperation Agency (JICA) or the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) are increasingly active to design support structures for microgrid projects.

International development banks such as the World Bank are potential investors in microgrid projects. The minimum investment volume is generally high, starting from EUR 5 million, and due diligence processes are long, risky, and expensive. However, if complementary foreign investment guarantees are part of the investment package, the application can still be worth the time and money spent. The Multilateral Investment Guarantee Agency (MIGA), a member of the World Bank Group, provides coverage for currency and country related risks, a risk mitigation option which may play a larger role in the up-scaling of investment activities in micrograds in the near future, as well as related products of international reinsurance corporations.

Microgrid developers face challenges due to the partly nonexistent, partly contradictory, and totally diverse legal and regulative frameworks in different countries. National governments and national utilities on the other hand, find it difficult to respond to the market entry of microgrids due to their plans for grid extension. The price structure for microgrids needs to be compared with the tariff that applies to the main grid, which is usually heavily subsidized for end users. Political deliberations are highly sensitive to the issue of discriminating customers, who face significant price gaps between on-grid and off-grid power supplies. The tariff collection is implemented more and more through “pay as you go” models which use mobile phone payments to collect money, pursuing a fully decentralized approach to manage financial transactions (Peterschmidt et al., 2013).

Countries with no deregulation of their power market practically inhibit private companies to develop microgrids, unless the nationally owned utility is directly involved. In fully monopolized or oligopolized power markets, private capital does not find adequate opportunities to invest. The dynamics of microgrid electrification and grid extension are then exclusively managed by governments, public regulators and the national utilities. In other countries where the rural power market is partly deregulated, i.e. in Tanzania, private developers and investors find a regulatory framework conducive to building business cases for village electrification (Tenenbaum et al., 2014). Yet, even in such a friendlier political environment private companies find it hard to obtain licenses to develop village electrification beyond pilot projects and to get approval for their proposed tariffs. Given the widespread corruption in many countries in Africa and Asia, the private sector is often challenged how to respond to national and regional officials who may be prone to accepting bribes throughout the application process (Tenenbaum et al., 2014). Political intervention by multinational organizations, development banks and international NGOs (e.g. Transparency International) as a way of last resort is risky. A public demarche and confrontation with the national authorities will in most cases jeopardize the project.

Given the often opaque power structures at the national level, the involvement of the village communities is a crucial success factor. The implementation of an off-grid microgrid always requires a high level of community consensus and support regarding payment collection procedures, service and maintenance, and ownership issues. Local participation is a key factor in the design of a successful business case. Single operator models of private developers, operators, and investors often overlook the importance of an inclusive approach towards village electrification. They fail to integrate their projects in the local social, economic, and cultural context (Peterschmidt et al., 2013).

Although community participation is now widely accepted as a prerequisite to ensure equity and sustainability of local infrastructure investments, a switch to total community ownership of a microgrid, including service and maintenance, has shown mixed results, at best. When power demand is steadily growing and there is an urgent demand from end users for the extension of the microgrid, the complexities of managing such growth and the need for technical know-how often overstretch the capabilities of village communities if there is no external assistance. The planning of rural electrification by a community is best facilitated by partners who can explain the options in simple terms, as off-grid communities will normally not be familiar with the technology or the implications of the choices – a fundamental issue already highlighted 15 years ago (Rai, 2000).

3.3. C. Innovative approaches towards more dynamic microgrids

Several authors emphasize the virtues of a modular approach to electrification (Tenenbaum et al., 2014). Such an approach has been used in Tanzania. A 24 V direct current system provides electricity from small generation and storage points which are scattered around a village to supply several households and small businesses. Each of these generation points has a capacity of less than 100 W. Through this modular system design, further storage and generation capacity can be added based on developing need at comparatively small supplementary capital requirements. Each user is equipped with a smart pre-paid meter, which is connected to a mobile money payment system, eliminating the risks involved in physical money exchanges (Tenenbaum et al., 2014).

3.4. Lessons learned from Microgrids in the Global South

As a conclusion of Chapter 3, Table 1 gives an overview of the lessons learned from microgrid implementation in the Global South.

4. Renewable energy communities in Germany

The legal framework of the German Energy Transition was laid in 2011. It was founded on a cascade of prior legal steps to advance renewable energy, most of which were pushed by a bottom-up movement. The political will to advance renewable energies was the result of citizens' concerns about the dangers of nuclear power and the rising awareness of climate change. Long-term goals to change the energy system have been identified and communicated by the government. By 2050, 60% of primary energy consumption and 80% of gross electricity consumption shall be produced from renewable sources. By 2022, the last nuclear power plant is scheduled to go offline (Die Bundesregierung, 2015).

In 2014, the share of renewable energy in primary energy consumption in Germany has risen to 12.4%. The renewable energy share of gross electricity consumption has risen to 32.5% in the first half of 2015, mostly attributable to onshore wind and photovoltaic power. The renewable energy share of final energy consumption for heating has risen to 9.9% (BMWi, 2015).

One key element in the energy transition is the so-called “Renewable Energy Sources Act” (EEG), supporting the installation of renewable energies by introducing technology-specific feed-in tariffs. Since its implementation in 2000, the EEG has been adapted several times, most recently in 2014. The EEG requires transmission and distribution system operators to connect renewable energy technologies to the grid, to accept the entire electrical output produced by them, and to remunerate the producers at a predetermined rate for the produced electricity. The remuneration is guaranteed for 20 years. Its rate depends on the time of installation.

This legal framework has laid the base for the rapid expansion of renewable energies in Germany. By providing that kind of long-term security for investment, it opened the door for many small investors and grassroots initiatives that could participate and also benefit from installing decentralized renewable energy systems. In

Table 1
Lessons learned are drawn from microgrid cases in the Global South across all categories of analysis.

Ownership and participation	There is a strong tendency of increase in demand of electricity, but the pace is not predictable. [A]
	Number of customers only stabilized after several years of operation in Sandwip. [A]
	People take initiative and connect themselves to their neighbors when the operator would not allow them to connect. [A]
	Tariffs create a sense of ownership for the case in Maharashtra, India. [A]
	Social engineering, independent of the technical and financial operation is important for the case in Chhattisgarh, India. [A]
	Local participation is the key to success. [B]
	Off-grid communities are likely not be familiar with the technology. [B]
Technology and system design	Parallel infrastructure was developed to improve reliability of systems or for prioritized load shedding. [A]
	Solar home systems continued to play an important role in Sandwip, even after the installation of the microgrid. [A]
	Grid-standard distribution grids and separate feeder lines assured reliable supply for the case in Maharashtra, India. [A]
	A 24 V modular grid using direct current and smart meters provides energy access and easy extensibility in Tanzania. [C]
Policy development and financing	Microgrids are perceived as a stopgap technology by some official authorities. [A]
	Unclear policy framework hinders investment. [B]
	Large perceived risks make financing difficult. [B]
	Large donor interest in microgrids. [B]
	Investments start at USD 5 Million for development banks. [B]
	Political environment is very sensitive to price gaps between on- and off-grid supply. [B]
	High perception of corruption is a major risk factor. [B]

2010, 51% of all renewable energy generation facilities were owned by private citizens, mainly organized in cooperatives, and 11% of these were owned by farmers (Morris and Pehnt, 2012).

Survey results reveal the strong support for renewable energies in the population. In 2014, 92% of the German population supported further growth of renewable energy usage, 70% found it “very or extremely important” (Morris and Pehnt, 2015, p.96), 22% found it important, and only seven percent found it less important or not at all important (Morris and Pehnt, 2015).

Since 2007, data on so-called “100 percent renewable energy regions” has been gathered. Under the framework of the project “100ee-Regionen” (IdE, 2015). These regions are still connected to the main grid. However, they are formally committed to achieving or have already achieved 100 percent renewable energy supply, in terms of the total amount of energy used and generated throughout the year. They manage their own energy supply system based on various renewable sources. As except for a few very remote locations, all German consumers are connected to the main grid, these regions can of course not be called “off-grid”. Yet, because of their endeavor to be self-reliant in their energy supply, they have already reached a relatively high degree of energy autonomy. The ones that have achieved 100% renewable energy supply did so based on production and consumption data in yearly balances and can be called “net energy neutral” (Rae and Bradley, 2012, p.6500).

The map shown in Fig. 5 highlights the 87 “100%-RE regions” (darker shading) who target a 100% renewable energy supply. In addition, 59 “100%-RE starter regions” (lighter shading) who show first efforts towards renewable energy deployment are displayed. The map also shows three “100%-RE urban regions” who demonstrate a strong leadership in scaling up renewable energies in an urban context (IdE, 2015).

As stated above, grassroots action was a key driving force in establishing and broadening the acceptance and policy development for the German energy transition. As 1.5 million PV plants of

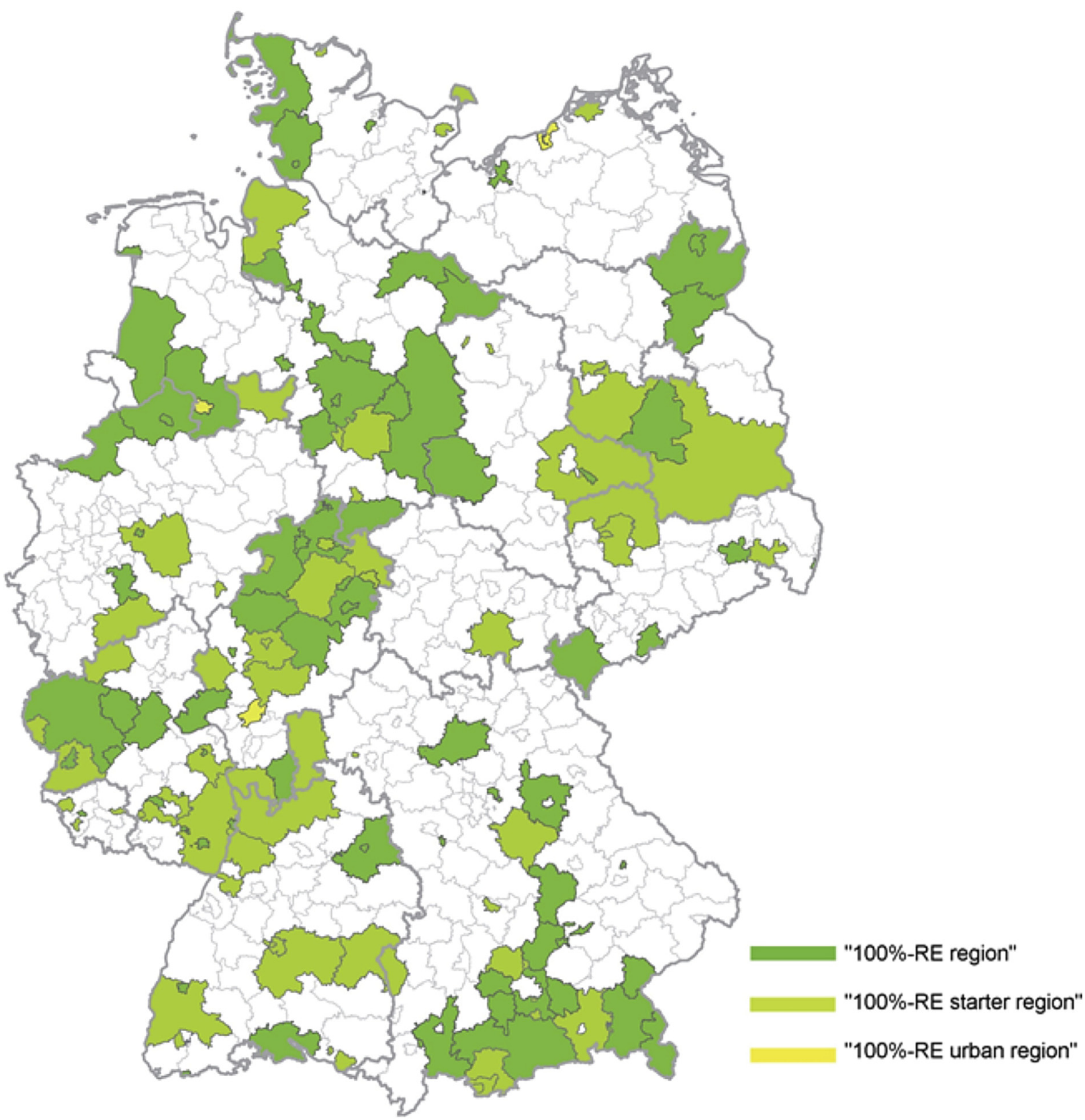

Fig. 5. Regions committed to 100% renewable energy are established across Germany. Source (IdE, 2015).

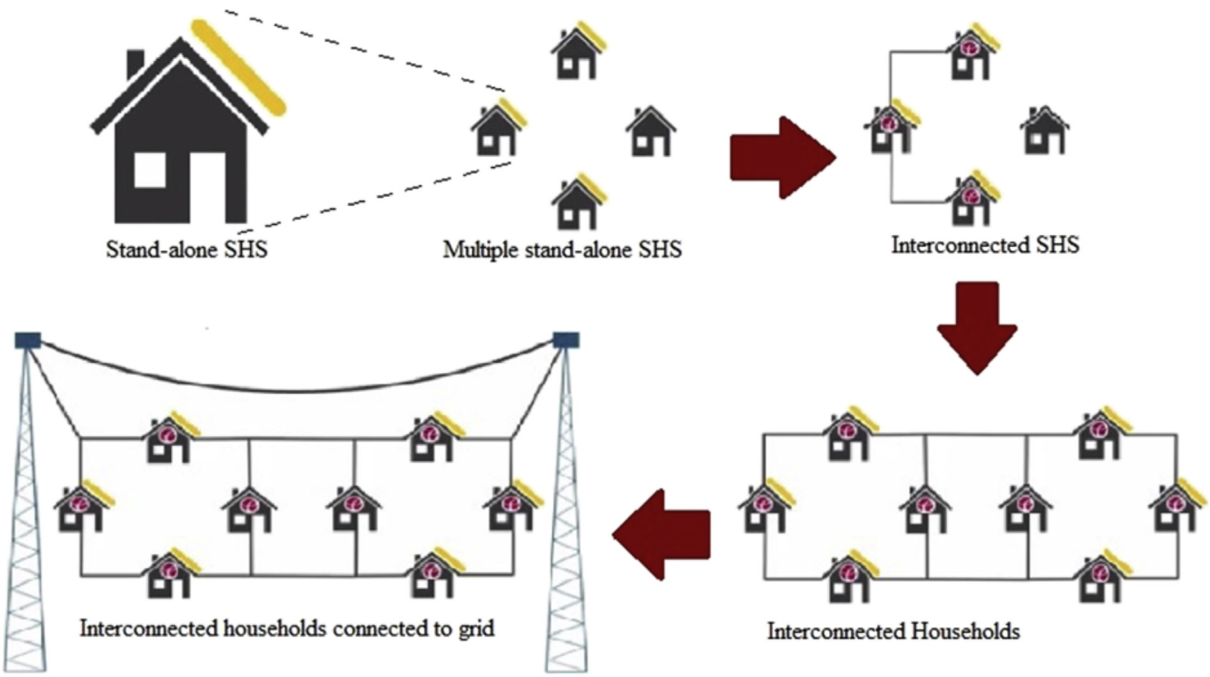

Fig. 6. Swarm Electrification is a step-by-step electrification concept. Source (Groh et al., 2014).

varying sizes have been installed, consumers turned into prosumers who also produce electricity. Various platforms for dialog have been established, for instance a virtual citizen dialog on the expansion of the electricity grids (Ahmels, 2015).

Public action and participation have been key factors to successful implementation of renewable energy infrastructure. Initially, individual households and communities investing in renewable energies were particularly active. This driving force is now extended to regions and is clearly visible in the implementation of the 100%-RE regions. These regions represent the next step where communities organize and cooperate to advance renewable energies.

All selected regions have in common that they value public participation and have established dialog structures leading to a common understanding (Müller, 2014). Most have also formed citizen energy cooperatives and some are planning to take over their local distribution grid (IdE, 2012). According to the ee100-region network, the key success factors are public participation, stakeholder dialog and ownership (Benz et al., 2010).

The modes of participation are manifold and include:

- Direct democracy instruments like referendums on a village level,
- stakeholder dialogs and stakeholder-focused decision making,
- developer-led and community owned implementation,
- community-led implementation and
- cooperatives owning the microgrids and electricity production facilities.

The remainder of this Chapter is split into three subsections, giving details on the role of cooperatives in general [A], the case of a Feldheim [B] and the case of Schönau [C].

4.1. The role of "Bürgerenergie" including cooperatives in the German energy transition

As mentioned above, the German energy transition has benefitted greatly from the so-called "Bürgerenergie". In 2010, the capacity installed by citizen-owned cooperatives and other forms of decentralized owners has been more than four times that of the capacity installed by large energy providers and utilities. Cooperatives offer the possibility of direct participation to everyone as they are not predominantly focused on economic benefits, but rather on following a common goal. The implementation of the feed-in tariff sparked a boom in the establishment of cooperatives (Engerer, 2014). By the beginning of 2015, Germany had 973 registered energy cooperatives (Müller, 2014). That Figure represents a steep increase from just a little under 100 cooperatives in 2006 (Müller and Holstenkamp, 2015).

The highest motivation for participation stems from the wish to support the energy transition in general. The prospect of a sound financial investment is, however, also a motivating factor. Yet, when asked, people showed a stronger interest in supporting environmental and social goals at the expense of and even foregoing financial benefits (Degenhart and Nestle, 2014).

With the implementation of renewable energy technologies by cooperatives and individuals, electricity supply has been partly decentralized. Research indicates that the kind of sense of ownership as well as actual ownership generated by this shift has proven successful in driving energy autonomy and energy transition. Research also suggests that energy cooperatives help to lower barriers to the implementation of renewable energy technologies by proclaiming and implementing various forms of benefits such as low prices, distribution of financial gains, complementary servicing of facilities as well as raising awareness and offering education on renewable energies (Viardot, 2013).

4.2. Example Feldheim: developer-led, community co-owned

One example of a developer-led community co-owned 100%-RE community is the village of Feldheim, which is part of the larger town of Treuenbrietzen in Brandenburg. In 2012, Feldheim had about 150 inhabitants. The project is characterized by an"excellent partnership between the municipality of Treuenbrietzen, the inhabitants of Feldheim and the project developer, Energiequelle

GmbH"(Raschemann, 2010, p.1). In 1995, Energiequelle built a wind turbine with the consent of the local residents. The wind park was later increased to currently 43 wind turbines with a total generation capacity of 74 MW.

In 2008, a biogas plant with 500 kW power capacity was built. The decision to construct the biogas plant was fueled by declining prices for agricultural products. With the added wood chip district heating plant, the heating power generated of 3.8 GW h/a is enough to heat all residential buildings. It also generates electricity of 4 GW h/a and produces about 12.000 m^3 of fertilizer per year. A photovoltaic power plant with 2.25 MW followed (Raschemann 2010, 2012).

In 2008, the citizens decided to buy the local electricity grid. However, the utility company owning the grid refused to sell it. Instead, a new distribution grid was established by Feldheim and Energiequelle with the financial contribution of each community member. The distribution grid was completed in 2010, exceeding local standards as per special regulatory request by the authorities and providing uninterrupted electricity supply (Guevara-Stone, 2014). Today the energy-providing company comprises 49 partners: residents of Feldheim, the town of Treuenbrietzen and Energiequelle Management GmbH. Although roughly 50% of the overall investment came from public sources, the remainder was raised from the community members and from the free market. In return, residents achieved a reduction in energy prices and the unemployment rate decreased considerably (Guevara-Stone, 2014). In Feldheim, the developer Energiequelle emphasizes that it has been aware of the need to involve the local community from the start during the planning, through the implementation, throughout the operation and on to the following steps of expanding the infrastructure.

4.3. Example grassroots campaign Schönau

The local energy utility company of Schönau in Southern Germany advertises itself as nuclear-free, climate-friendly and owned by its citizens (Komenda et al., 2015). The case of Schönau is widely cited as an example for one of the first energy cooperatives turning an entire city to use solely renewable energy on average. Schönau had 2300 inhabitants in 2013. In 1986, after the nuclear accident in Tschernobyl, citizens formed an initiative to become independent from nuclear power and to establish a renewable energy infrastructure. Today, it is a major provider of renewable electricity in Germany with 150.000 customers in 2012 (Ernst, 2014).

As a first step, it was decided to buy back the local grid. In 1991, a first citizen's referendum was initiated. The citizens voted in favor of stopping the municipality from giving another concession over 20 years to the local energy utility and to actually acquire the local electricity grid. This led to the formation of the energy utility Schönau in 1994. The energy utility was then owned by 650 citizens and in 1995 managed to secure the local concession.

In 1996, a second referendum, this time initiated by the opposition to stop the cooperative from buying the local grid, was rejected. In order to raise the sum needed to actually buy the local grid, the initiative secured over EUR 1 Million in citizen loans in a campaign. From 1997 on, it has started building renewable energy power plants. From 1998 on, the utility sold solar electricity to private households all over Germany (Graichen et al., 2001; Dijkstra and Graichen, 2000). In 2009, it also acquired the concession to operate the natural gas network. In 2010, 2011, it branched out to neighboring communities. In 2009, the utility became a cooperative with over 2.700 members.

In the case of Schönau, the process was driven by a group of individuals. Initially, the group had no technical knowledge about energy systems but the will to establish renewable energies as an alternative to nuclear power. They acquired all of the required knowledge: technical, procedural, financial or legal along the way. The generation capacity was increased successively in line with available funding and based on the public approval. Today the energy utility Schönau is one of the leading national renewable electricity providers.

4.4. Lessons learned from Microgrids in the Germany.

As a conclusion of Chapter 3, Table 2 gives an overview of the lessons learned from microgrid implementation in Germany

5. Analysis: development and application of mutual success factors

Even though microgrids in the Global South and 100%-RE communities in Germany are situated in very different environments, there are valuable lessons for mutual learning. This section is separated into the following three categories of analysis: 1) Ownership and participation, 2) technology and system design, and 3) policy and finances. All sections refer to Tables 1 and 2, which are the syntheses of Chapters 3 and 4, respectively.

5.1. Ownership and participation

Cases of microgrids in the Global South indicate a large variety of social factors that play a role in their successful implementation. A large amount of resources is allocated to the initial feasibility study, to raising public awareness and generating public participation and ownership in the village. However, in the Global South, the use of the word "ownership" usually refers only to the more abstract form in the sense of responsibility to use and maintain the microgrid, rather than to the literal financial contribution. The 100%-RE communities in Germany could usually base their level of financial independence on a higher ability of the users to share in the financing of the high upfront investment cost of renewable energy infrastructure. Through the creation of cooperatives, motivation and literal ownership for the joint undertaking could be increased. The ability to be recognized and be able to act as a legal entity also helped the cooperatives to acquire and hold assets. As microgrids have become more modular, starting with smaller initial setups and capital requirements, the ability for local ownership is also increasing in the Global South.

5.2. Extracted success factors

- **Sense of ownership established:** The sense of ownership for the established technical system should be as high as possible. Integrating community works such as volunteered labor contributions, reliably committed financial contributions, and a legal framework for the community organization add to the "soft factors" of a well-run microgrid.
- **Users are prosumers:** A strong shift in perspective is achieved by assuring that consumers are also producers of electricity: either through their individually owned assets, or through their jointly owned assets.
- **Ability to understand technology:** As communities are unlikely familiar with the technology and its requirements, consulting outside expertise is crucial for their ability to make informed decisions.

5.3. Technology and system design

A key difference between cases is the inability of off-grid communities to rely on grid electricity as back-up in case of under-

Table 2
Lessons learned are drawn from microgrid cases in Germany across the categories of analysis.

	Lessons learned from Germany's 100%-RE communities
Ownership and participation	Shift from pure consumer to prosumer level increases the support in the energy transition. [A]
	Community spirit can act as a strong driving force. [A]
	Cooperatives can also set the right framework for "soft factors" like public awareness and community building. [A]
	Renewable energies themselves were the driving factor which motivated electricity users to increase the political pressure. [A]
	Existing cooperative structures can bring together inhomogeneous stakeholder groups and help energy communities get started (e.g. bioenergy cooperatives on the basis of agricultural cooperatives). [A]
	Public participation, stakeholder dialog, and ownership are key success factors for 100%-RE regions. [A]
	Resistance of utilities and grid operators was overcome by a local, end-user financed distribution grid development. [B]
	A strong personal commitment of one or more individuals from either inside the village [C] or from outside [B] can serve as a crystallization point and driving factor.
Technology and system design	Local authorities had to be convinced that reliability of supply would be beyond standards prior to the approval for a new distribution grid development in Feldheim. [B]
	In all cases the generation capacity was added successively one segment at a time in line with available funding and based on public decision. [B] [C]
	The local energy utility in Schönau started with acquiring the local distribution grid and then with the construction of renewable energy generation capacity. [C]
	Resistance by the existing operator of the grid had to be overcome in order to purchase the grid. This resulted in a much higher price for it. A Germany-wide public campaign raised the money to pay the bill. [C]
Policy development and financing	The introduction of feed-in tariffs in the "Renewable Energy Sources Act" (EEG), triggered the development of cooperatives in Germany. [A].
	Public sources supplied 50% of the project funding for Feldheim. [B]
	Unemployment decreased considerably in Feldheim due to the strong local economy associated with electricity generation and management. [B]
	Generally, the implementation of renewable energy leads to the establishment of local value chains and local economic value added and unemployment decreases. [A] [B]
	Literal ownership of the production facilities by cooperatives creates individual acceptance along with economic gains, e.g. lower electricity prices. [A] [B]
	Owners are willing to accept lower economic returns on their investment in cooperatives because of their strong support of RE. [A]
	An external shock (Chernobyl and Fukushima) was the starting point for the grassroots movement in Schönau, [C] and again for the public pressure to phase out nuclear energy (Fukushima). [A]

supply as opposed to the German 100%-RE community cases, which are all grid-connected. This has direct implications on the lessons learned as the microgrids are much more dependent on the local availability and reliability of the renewable energy source and storage. Regardless of this distinctive difference, both settings face high technical expectations from the general public and users. The design of the of the electricity lines is critical for the energy transfer across the community. This binding element between points of generation and usage is increasingly accompanied with an information layer, allowing for smart grid implementations.

5.4. Extracted success factors

- **Technology ready to evolve:** High technical standards for the installation of the lines and cables with the option of extension and connection to the main grid are to be set. The increase of load and number of customers can be very dynamic but is difficult to predict.
- **Smart grid elements for transparency:** Smart grid elements are critical for system balance and increase the level of trust among stakeholders. Smart tariffs become implementable.
- **Assure energy service provision:** Service delivery needs to be assured even when electricity generation from renewable energy sources fluctuates. A certain degree of individual self-reliance is increased when decentralized storage is introduced.

5.5. Policy and financing

Despite large interest of donor organizations in the off-grid sector development, large differences in terms of financial abilities are observed when considering the Global South and Germany. However, in both cases, policies in favor of renewable energy integration have fostered their growth, and public funding plays a major role. The perceived risks are generally very high for the Global South, but are particularly high for microgrid implementations, as the investment value is also subject to the governments' decisions on future public grid expansions.

5.6. Extracted success factors

- **Include private sector investment:** Sources of financing cannot only rely on the public sector. Additionally, acquisition of funding for a combination of microgrid projects may be a promising route for financing.
- **Cost-recovering tariffs:** Policy development needs to focus on cost-recovering price ranges such as feed-in tariffs to attract investment, as was the case for Germany.
- **Target long-term solutions:** International examples of self-sustaining communities have the potential to alter the perspective of a microgrid of being a stopgap way of electrification, but a sustainable energy access model.

5.7. Application of the Success Factors to Swarm Electrification

To demonstrate the application of the success factors, the analysis chapter concludes with an application of the success factor on Swarm Electrification. This concept is novel in its bottom-up and peer-to-peer character. It was chosen for this paper to demonstrate the potential and limitations of the success factors developed. A brief description of the approach is given below, for a detailed insight into the approach, the reader is directed to the respective literature (Groh et al., 2014).

Swarm Electrification was developed as an energy efficient peer to peer microgrid system. The concept builds on a bottom-up coming from the electricity users (Groh et al., 2014). It is based on the integration of existing energy infrastructures at the household level and the interconnection of those to a small microgrid (see Fig. 6). As a result, a "swarm" of prosumers is able to share electricity among each other and cover different loads and usage patterns, while the overall capacity can be increased dynamically in a modular way. The concept results in an energy sharing platform.

Table 3
The identified success factors are applied to Swarm Electrification.

		Score
Ownership and participation:		
Sense of ownership established	The swarm microgrid builds on already existing infrastructure.	1
Users are prosumers	Microgrid users are both consumers and producers, but some users may also join without the ability to produce electricity.	1
Ability to understand technology	The technology itself is complex, but builds on existing user experience of previously installed solar home systems.	0.5
Technology and system design:		
Technology ready to evolve	The concept builds on the dynamic evolvement of the infrastructure.	1
Smart grid elements for transparency	Smart meters are proposed.	1
Assure energy service provision	Relies mostly on solar power, but privately owned storage systems assure high autonomy.	1
Policy and financing:		
Include private sector investment	Private sector is mentioned as a possible vehicle for implementation.	0.5
Cost-recovering tariffs	The concept acts like a platform, the tariff is subject to local negotiations between different users and likely to be cost-recovering.	1
Target long-term solution	The approach foresees a promising future for microgrids.	1
Total score		8 of 9

The platform allows every user to become both: producer and consumer. Swarm Electrification has strong similarities to the concept of “Schwarmstrom” that has been put forward for the electricity sector transition in Germany with decentralized generation units (Kampwirth, 2009).

The success factors are applied in Table 3. This step-by-step, sharing-based approach that builds on existing user-owned assets is in line with the success factors.

6. Conclusion and next steps

NGOs and community action groups in Germany have faced a number of challenges to “localize” power generation and distribution. It is shown in this work that microgrid actors in the Global South are confronted with similar challenges. With the liberalization of the electricity market in the 1990s and the German renewable energy feed-in law in 2000, bottom-up initiatives have gained substantial political power over the last 20 years. However, it took considerable and consistent effort to change the status quo and establish new concepts of economics and new concepts of financing. Stakeholder buy-in, ownership, and public acceptance are all factors that matter.

Different examples from the Global South indicate that the agenda here has other priorities. Affordable access to energy is more important than the increase in renewable energy generation capacity per se. This different focus has led to different organizational and technical models, aiming at creating cost-effective platforms for energy supply. While microgrids are increasingly important in the market of off-grid solutions, individual electrification systems continue to play an important role. Some users opted for parallel infrastructures such as a solar home system and the connection to a microgrid to make best use of renewable resources available.

Both in the 100%-RE community examples in Germany as well as for the microgrids in the Global South, strong initiatives from users indicate a key role for bottom-up approaches. Top-down mechanisms in particular in regard to technology design and standards have their place in both settings.

The key contribution of this paper to the research community is the synthesis of nine success factors for renewable-powered microgrid implementation. These fall along the categories of ownership and participation, technology and system design, as well as policy and financing. The success factors are based on lessons learned that microgrids in the Global South and 100%-RE communities in Germany share. The applicability of lessons learned in Germany to the context of microgrids in the Global South is limited by the available resources on hand, in particular with regards to financial capital. The analysis section concludes with an application of the success factors to a bottom-up microgrid concept framed as “Swarm Electrification”, which is discussed in the literature as a sharing-based electrification scheme. The analysis showed that Swarm Electrification already provides many attributes of the success factors, making it a highly promising approach for renewable energy-based electrification.

Further research should focus on evaluating the applicability of the derived success factors presented in this paper and developing them further. Moreover, research is needed to elaborate on methodologies for cross-study analysis in the context of energy access in more detail.

Acknowledgments

This research was supported by a PhD-scholarship of the Hans-Böckler Foundation which is funded by the Federal Ministry of Education and Research (Germany).

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