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Editorial

Multispecies Swarm Electrification for Rural Areas of the Developing World

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Abstract: Today, 992 million people still do not have access to electricity globally. Most live in rural areas of the developing world. In 2018, the electrification rate for sub-Saharan Africa was only 27%. Furthermore, off-grid systems are projected to provide 65% of the newly electrified population in sub-Saharan Africa. Current estimations show that the average connection cost per technology in rural areas of sub-Saharan Africa is 2000–3000 USD for grid extension, 500–1200 USD for a microgrid solution, and 150–500 USD for a solar home system. The most recent studies for real-world microgrids installed in sub-Saharan Africa show that the average split of capital expenditure (CAPEX) spending on distribution versus generation in microgrids is at 50%/50%. This is the result of the significant cost reduction of photovoltaics, batteries, and power electronics, in comparison with the practically stable unchanged cost of poles and cables. Even if the business model is chosen by the investor—usually a pay-as-you-go implementation—there is still the difficult decision to make on whether to go for a microgrid or solar home systems. Taking inspiration from multispecies swarms, a Multispecies Swarm Electrification approach is developed that is able to meet the real-world needs of the developing world in terms of rural electrification.

Keywords: rural electrification; multispecies swarms; microgrids; solar home systems

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Today, 992 million people still do not have access to electricity globally [1]. Most live in rural areas of the developing world. In 2018, the electrification rate for sub-Saharan Africa is only 27% [1]. Microgrids are becoming a key player for cost-effective and reliable electrification of rural areas, and it is projected that one-third of the total investments toward achieving the 2030 Sustainable Development Goal 7 (SDG 7) of the United Nations for universal access will be targeting microgrids, powered mainly by renewables [2]. Furthermore, off-grid systems are projected to provide 65% of the newly electrified population in sub-Saharan Africa [3]. At the same time, solar home system market in Africa is booming—in the first half of 2018, 2.70 million products were sold with corresponding revenues of 107.50 million USD, a ~260% increase from the first half of 2017 [4]. The projected growth of this market is estimated at 1.3 billion USD by 2024 [5]. Pay-as-you-go and solar-as-service business models are becoming the major driving models for this market [6]. Current estimations show that the average connection cost per technology in rural areas of sub-Saharan Africa are 2000–3000 USD for grid extension, 500–1200 USD for a microgrid solution, and 150–500 USD for a solar home system [7]. It has to be highlighted, though, that measuring access can pose many difficulties for rural electrification since different systems (either microgrids or solar home systems) will provide different peak load, energy, etc. The multi-tier framework proposed in the Global Tracking Network of Sustainable Energy for All is a comprehensive approach on how to measure access [8]. When comparing the cost between different solutions, the provided energy access tier has also to be taken into consideration. Finally, the most recent studies for real-world microgrids installed in sub-Saharan Africa show that the average split of capital expenditure (CAPEX) spending on distribution versus generation in microgrids is at 50%/50% [9]. This is the result of the significant cost reduction of photovoltaics, batteries, and power electronics, in comparison with the practically stable unchanged cost of poles and cables. Even if the business model is chosen by the investor—usually a pay-as-you-go implementation—there is still the difficult decision to make on whether to go for a microgrid or solar home systems.

Swarm behavior is a collective behavior exhibited by entities, particularly animals, of similar size which aggregate together, perhaps milling about the same spot or perhaps moving en masse or migrating in some direction [10]. In biology, during the past years, research is taking place in multispecies swarms. It has been observed that microorganisms use collective migration to cross barriers and reach new habitats, and the ability to form motile swarms, a fact which presents a competitive advantage. Microorganisms can facilitate other species' dispersal by forming multispecies swarms, with mutual benefits creating, in essence, a moving ecosystem [11]. Taking inspiration from this, we envision a Multispecies Swarm Electrification approach that is able to meet the real-world needs of the developing world in terms of electrification (see Figure 1). In detail, three types of solar home systems (species) can be used on their own or interconnected independently to provide higher power/energy for dispersed loads. At the same time, they can be interconnected in a low voltage AC microgrid in the cases it makes economic sense to invest in grid infrastructure.

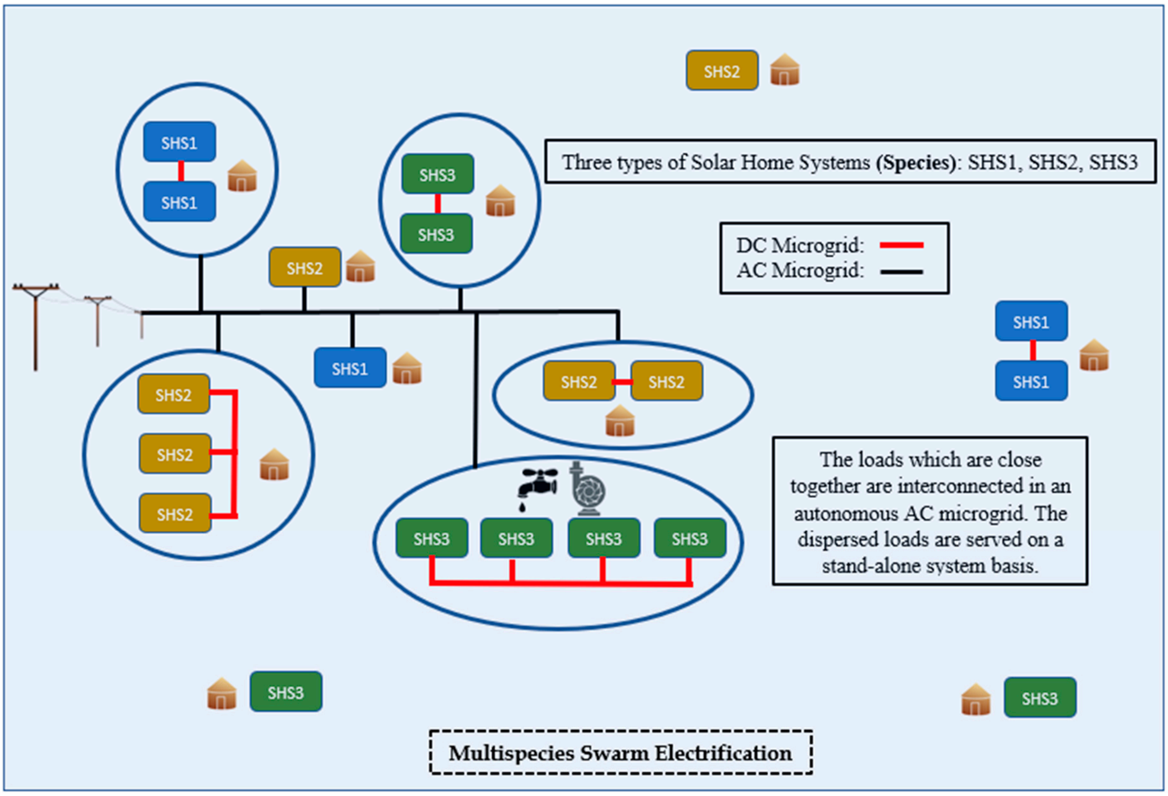

Figure 1. Multispecies Swarm Electrification Ecosystem.

The core concept of swarm electrification in a rural electrification context is based on the use of a solar home system technology, where each solar home system implementation is able *"out of the box"* to be interconnected with more thus forming, in the end, a low-voltage microgrid, without the use of any extra power electronics equipment. This is an ideal solution for rural and remote areas where high dispersion of households and loads is observed. Swarm electrification can allow the deployment of a single technology system in a given area, where some of the solar home systems that are closer together are interconnected from the start to form a microgrid and the rest have the ability to be interconnected to the microgrid in the future when more loads/households appear, making the investment in a microgrid extension viable.

Swarm electrification was first proposed for microgrids in the developed world as a more advanced microgrid approach where interconnections with the existing grid would be easier and it would provide more freedom to the people to build their own communities. In particular, in Germany, there were lots of groups from the beginning of the 2000s that wanted more autonomy in relation to their electrification from the main grid. In this fashion microgrids was their technology of choice. In 2009 there was a paper where swarm grids were first mentioned. It was a paper presenting research results from a German power company (LichtBlick) using also technology by Volkswagen [12]. This is now commercialized [13].

A research group (now called Microenergy systems research group) from the Technical University Berlin was the first to start investigating swarm electrification for the developing world. Their research started in the beginning of the 10s. Some of the initial researchers have now formed Micro Energy International which includes a research think tank, a consulting company, a research laboratory, and a spin-off company from the university that is selling such systems in Bangladesh. Their technology is solely direct current (DC) based. Most research papers published by this group focus mostly on investigating the socioeconomic impacts in relation to the technology and not the actual technology [14–17]. The DC approach used is indeed fitting to the realities of South-East Asia where large urban and peri-urban populations who, due to their poverty, cannot connect with a grid but can buy solar home systems. Due to the dispersed nature of most populations in rural sub-Saharan Africa, this approach is not applicable.

Powerblox is a Swiss-based company that sells a swarm electrification product for rural areas of the developing world. As is evident from the pending patent [18] of the company an internal DC bus allows the interconnection of a number of devices and then an AC bus allows connection with other such blocks of modules. While in the patent an installed power of over 1 MW is stated as possible, in reality, the commercial product has a limit of 3.6 kW which is the result of 9 blocks being interconnected together. Moreover, frequency control is also stated as the main control approach used, a technology that has been commercially available for over 15 years [19].

The investigation of the current state of the art shows that all research so far aims at the development of a single solar home system component to be used as the single building block of swarm electrification systems. This approach, while having the advantage of simplicity, fails to meet the range of loads addressed in the developing world adequately.

Taking inspiration from multispecies swarms, a Multispecies Swarm Electrification approach is developed that is able to meet the real-world needs of the developing world in terms of rural electrification.

The benefits of such an approach can be summarized as:

- An easily expandable and upgradable system to provide any tier access needed to any location using just 3 building blocks.
- A cost-effective approach since low-cost hardware can be utilized for the controllers/Energy Management System.
- It can operate in isolation (solar home system) or interconnected forming a microgrid.
- It can have an embedded smart metering solution to allow for a pay-as-you-go scheme, minimizing the cost for the investor.
- Through the extended metering infrastructure in the multispecies swarm, maintenance can be programmed in an easier manner and electricity theft monitored with accuracy.
- It simplifies and lowers the cost of designing, implementing, operating, and maintaining rural electrification projects.
- The above benefits do not increase the production cost of the base systems.

This Multispecies Swarm Electrification approach is currently further developed experimentally at the Agricultural University of Athens.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. IEA. *World Energy Outlook 2018*; IEA: Paris, France, 2018.
2. IBRD/WorldBank. *State of Electricity Access Report 2017*; IBRD/WorldBank: Washington, DC, USA, 2017.
3. Dagnachew, A.G.; Lucas, P.L.; Hof, A.F.; Gernaat, D.E.H.J.; de Boer, H.-S.; van Vuuren, D.P. The role of decentralized systems in providing universal electricity access in Sub-Saharan Africa—A model-based approach. *Energy* **2017**, *139*, 184–195. [CrossRef]
4. GOGLA. *Global Off-Grid Solar Market Report—Semi-Annual Sales and Impact Data*; GOGLA: Utrecht, The Netherlands, 2018.
5. GOGLA. *Global Off-Grid Solar Market Report—Semi-Annual Sales and Impact Data*; GOGLA: Utrecht, The Netherlands, 2017.
6. Scott, A.; Diecker, J.; Harrison, K.; Miller, C.; Hogarth, R.S.W. *Accelerating Access to Electricity in Africa with Off-Grid Solar—The Market for Solar Household Solutions*; ODI: London, UK, 2016.
7. Butare, A.; Kyriakarakos, G. *Guidelines for Institutional and Policy Model for Micro-/Mini-Grids*; EU Technical Assistance Facility for Sustainable Energy for the benefit of the African Union Commission: Addis Ababa, Ethiopia, 2018.
8. Bhatia, M.; Angelou, N. *Beyond Connections—Energy Access Redefined*; World Bank Group: Washington, DC, USA, 2015.
9. International Finance Corporation, World Bank Group. *Benchmarking Mini-Grid DESCOs 2017 Update—Summary of Findings*; IFC: Washington, DC, USA, 2018.
10. Swarm Behaviour. Available online: https://en.wikipedia.org/wiki/Swarm_behaviour (accessed on 2 August 2019).
11. Ben-Jacob, E.; Finkelshtein, A.; Ariel, G.; Ingham, C. Multispecies Swarms of Social Microorganisms as Moving Ecosystems. *Trends Microbiol.* **2016**, *24*, 257–269. [CrossRef] [PubMed]
12. Kampwirth, R. *SchwarmStrom—Die Energie Der Zukunft*; LichtBlick: Hamburg, Germany, 2009.
13. SchwarmEnergie®: Intelligente Energie Für Ein Neues Energiezeitalter. Available online: https://www.lichtblick.de/schwarmenergie/ (accessed on 2 August 2019).
14. Fairley, P. "Swarm electrification" powers villages [Resources_Startups]. *IEEE Spectr.* **2018**, *55*, 21. [CrossRef]
15. Groh, S.; Koepke, M. A System Complexity Approach to Swarm Electrification. In Proceedings of the International Symposium for Next Generation Infrastructure, Schloss Laxenburg, Vienna, Austria, 30 September–1 October 2015; pp. 283–290.
16. Koepke, M.; Groh, S. Against the Odds: The Potential of Swarm Electrification for Small Island Development States. *Energy Procedia* **2016**, *103*, 363–368. [CrossRef]
17. Kirchhoff, H.; Kebir, N.; Neumann, K.; Heller, P.W.; Strunz, K. Developing mutual success factors and their application to swarm electrification: Microgrids with 100% renewable energies in the Global South and Germany. *J. Clean. Prod.* **2016**, *128*, 190–200. [CrossRef]
18. Medici, A. Electric Energy Supply Unit and Controller for Same. Patent number WO2017215752A1, 21 December 2017.
19. Engler, A.; Meinhardt, M.; Rothert, M.; Wollny, M. New Generation of V/f-Statics Controlled Battery Inverter Sunny Island—The Key Component for AC Coupled Hybrid Systems and Mini Grids. In Proceedings of the 14th International Photovoltaic Science and Engineering Conference (PVSEC-14), Bangkok, Thailand, 26–30 January 2004.