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Prosumer Empowerment through Community Power Purchase Agreements: A Market Design for Swarm Grids

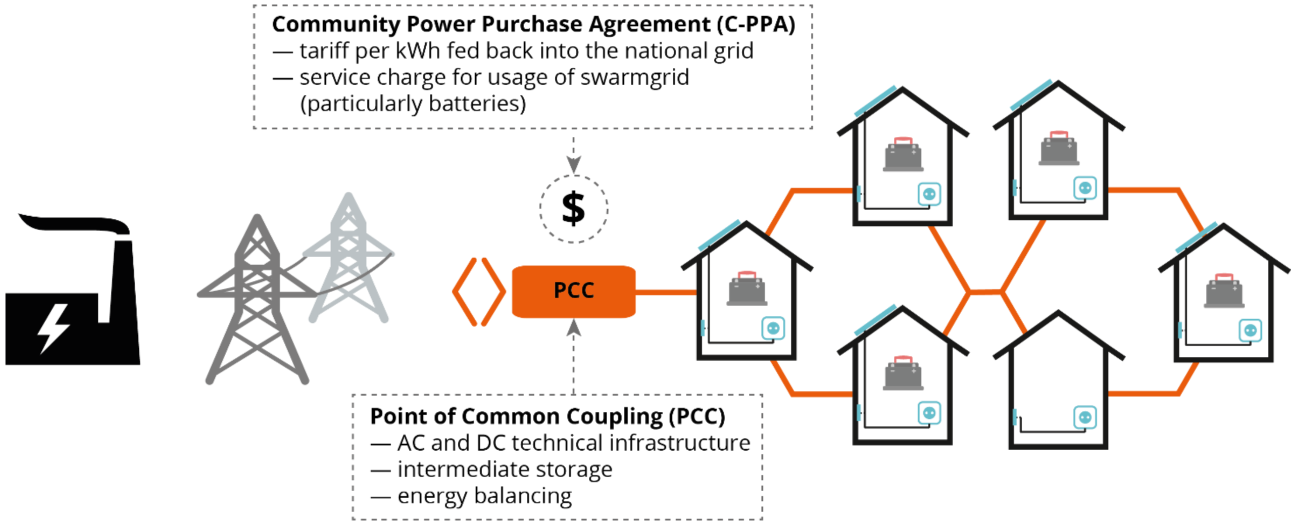
Raluca Dumitrescu[1], Alexandra Lüth[2], Jens Weibezahn[1,2,3], Sebastian Groh[4]
[1]MicroEnergy Systems Research Group, Technische Universität Berlin, [2]Copenhagen School of Energy Infrastructure (CSEI), Copenhagen Business School (CBS) [3]Workgroup for Infrastructure Policy (WIP), Technische Universität Berlin, [4]BRAC Business School (BBS), BRAC University

To achieve the United Nation's Sustainable Development Goal 7 "Clean and Affordable Energy", the most economically viable option for servicing the part of the population that is too remote or for which the national grid extension is too expensive are distributed renewable energy solutions (DREs), that is, standalone solar home systems (SHSs), mini grids, and swarm grids[1]. By 2030, more than 290 million people could be connected to mini grids. Following a top-down approach to electricity access, countries of the Global South, with support of international aid and development funding, are accelerating their national grid expansion. As the national grid reaches their customers, the private sector (DRE companies) is put at danger of having to either relocate their assets or abandon them. At the same time, the DRE end-user, reached by the national grid, faces several challenges due to being exposed to a double infrastructure. These challenges can be of technical and financial nature and are caused by the assets becoming abundant or needing additional equipment to be suitable for national grid and DREs. In our new paper we investigate a technically and economically viable solution for the co-existence of the national grid—a centralized infrastructure—with mostly decentralized, renewable energy infrastructure in Global South countries. At the intersection of these two electrification pathways the question arises if the two approaches can be integrated to the benefit of society by maintaining existing assets. We assume the technical link to be a bidirectional inverter and a battery representing the point of common coupling (PCC) between national grid and currently off-grid systems. We then suggest to apply a cost recovery approach to calculate the economic value of a community power purchase agreement (C-PPA) that allows the community to enter into a trade agreement with the national grid to export at a specified rate.

Integrating two distinct electricity infrastructures (one centralized–the national grid, the other decentralized–the swarm grid) and two electricity markets (one centralized–encompassing consumers, the other decentralized–renewable energy prosumers) can be done technically, through the PCC, and regulatory and economically synergetic through the C-PPA, see Figure 1. The results show that for each of the stakeholders active in the new energy infrastructure, several benefits, limitations, and risk mitigation strategies can be derived.

Prosumers benefit on several levels. Rural households generate revenue from the sale of the surplus electricity into the national grid and are compensated by the national grid for the utilization of prosumers' generation (PV panel) and storage (battery) assets. Through the unfettered access to electricity, bigger loads (productive use appliances) can be used, thus diversifying the economic activities within the community. And through the integration of the two electricity infrastructures, the households are no longer required to invest in new appliances (to account for the AC/DC connections). Also, some risks are mitigated: as the PCC enables the bidirectional transfer of electricity between the national grid and the swarm grid, households have 24/7 access to a source of electricity, eliminating the need of complementary generation sources (hence avoiding an investment in local fossil-fuel based technology, such as diesel generators). In case of national grid failures, the swarm grid can continue to function in "island" mode, hence the households' access to electricity is uninterrupted. These benefits might be limited by a possibly low community social buy-in due to unclear ownership roles for generation and storage within the swarm grid, and by extension, the C-PPA compensation for the prosumer.

The private **swarm grid operator** also benefits from the PCC/C-PPA setting. Through access to the national grid as a source of additional electricity, investment in additional micro utilities is avoided and the payback time of the existing micro utilities is reduced. As the swarm grid



Community Power Purchase Agreement (C-PPA)
— tariff per kWh fed back into the national grid
— service charge for usage of swarmgrid (particularly batteries)

Point of Common Coupling (PCC)
— AC and DC technical infrastructure
— intermediate storage
— energy balancing

Figure 1: PCC and C-PPA layout.

interconnection to the national grid becomes more complex, in the future, new ancillary grid services could be provided, diversifying the operator's business and operational model. On the risk mitigation side, the swarm operator is no longer in the position of having to abandon or relocate the decentralized grid, as the C-PPA contractual framework allows them to continue the business operations as an independent grid operator (IGO). However, the easiness with which the contractual C-PPA can be set up highly depends on the public sector institutional setup. Yet, the private operator needs to constantly monitor the performance of the swarm grid and of the nodes (SHSs) to assure that the optimal provision of ancillary grid services can be provided–otherwise, they risk being penalized (as in any PPA). In addition, the cost of the PCC should be taken over by the national utility as the implementation primarily benefits the national grid (for the increase of reliability and resilience in specific parts of the grid).

At the grid level, the **national utility** profits through the reduction of high costs for the interconnection of rural households, as a one-time PCC interconnection is cheaper than an individual household connection. A one-time PCC interconnection can reach a cluster of households, while through normal national grid expansion, distribution lines, transformers, and household meters need to be installed in order to reach each household. Technical failures in the grid (voltage spikes, frequency irregularities) can be serviced through the utilization of the newly integrated decentralized storage units and SHSs, the national utility is able to diversify its energy generation sources with renewables, instead of relying on traditional energy sources, contributing significantly to the country's NDCs. Additionally, there is a high potential of increasing the environmental impact, by sustainably interconnecting millions of SHS users that are not yet part of a swarm grid or not yet feeding into the national grid. The risk of losses due to failures to collect consumer payments are reduced or eliminated, as the activity is now outsourced to the IGO. The approach is limited, though, by the need for the national grid to be "smart" so that it can activate and utilize the full range of offered trade quantity and in the future potentially ancillary services provided by the swarm grid. Additionally, such services need to be quantifiable and monitored, so that they can be priced in the C-PPA.

Despite outlining many benefits, there are shortcomings in the setup of the C-PPA as a regulatory instrument. The integration of the two systems may only be achieved if the current financial support of the energy system can be re-balanced, allowing the C-PPA to become an instrument supporting clean energy supply. Currently, the model only considers the feed-in of electricity; theoretically, ancillary services could also be provided to the national grid, yet, as of today there is no framework for pricing these services.

Pilot projects in Uganda, and our case analysis in Bangladesh display modalities through which state utilities can leverage distributed private-sector business models to extend the grid to rural or remote areas and by doing so, make critical upgrades to their infrastructure. In this context, our analysis shows that through the introduction of a CPPA, multiple co-benefits can be achieved for the actors situated at the intersection of the two electrification pathways, while fighting climate change. Nevertheless, to assure the uptake of the C-PPA, a clear institutional setup and policy framework need to be in place. This implies several recommendations for the main actors:

State utilities need to define the grid interconnection requirements (i.e. delivery voltage, special requirements and conditions, point of supply, interconnection arrangement) so that the C-PPA can be accurately calculated. The **private sector** needs to be informed about the range of services it can provide to the national grid and the discussion to differentiate between a feed-in tariff and the C-PPA tariff need to be taken up. Finally, due to its better access to financing, the state utility should take over the cost of the DRE interconnection–in our case analysis, the cost of the PCC. Our estimations show that the cost of the PCC is lower than that of the grid extension and that its CAPEX can be recovered faster if the risk is taken over by the national utility. As the scenario analysis shows the OPEX of the newly interconnected infrastructure can be priced in the C-PPA. As the C-PPA is a derivation of a standard PPA, **energy regulators** (such as energy ministries or renewable energy agencies) need to ensure that the contractual framework is defined and standardized. Moreover, regulators could also consider setting up utility concessions that can allow the IGOs to obtain the rights to provide services under the C-PPA, under public sector oversight or public-private partnership (PPP). These PPPs are a means to leverage private capital and must have a clear legal structure balancing between ensuring adequate financial returns and meeting the public objectives of the governing agency, particularly given that the fundamental economics of grid-based rural electrification remain difficult. Finally, tracking and making public the costs incurred with the national grid extension and individual consumer interconnection could enable researchers, international development organizations, and policymakers in further investigating the cost-benefit analysis of centralized vs. decentralized electrification, in quantifying the investment required to reach the remaining unelectrified population, and in supporting more targeted policy recommendations.

References:

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[1] Swarm grids are built bottom-up, through the interconnection of decentralized renewable energy assets such as solar home systems. Mini grids can be defined as a set of centralized electricity generators (e.g. solar, diesel, hydro, wind) and possibly energy storage systems, connected to a distribution network that supplies electricity to a localized group of customers.