Print and shine: Printing applications for solar microgrid implementation in remote areas

Joël Hollander, Kristina Smieskova, Stan van den Bosch and Zata Amani (Wageningen University & Research, the Netherlands)

Key messages

- Organic and perovskite solar cells have a large potential in electrifying off-grid remote areas in the Global South through solar power systems as these technologies are easy to install, operate, maintain, and can be locally produced.
- A high sense of ownership and community participation is crucial for a successful inclusive, sustainable, and large-scale implementation of solar power systems for electrification in remote areas in the Global South. Organic and perovskite solar cells can contribute to increasing the sense of ownership and community participation.
- Compared to conventional solar cells, organic and perovskite solar cells offer a better economic and environmental sustainability. Respectively, organic and perovskite solar cells are projected to be more cost-efficient when upscaling its production and are more circular, due to the recyclability of both technologies and the biodegradability of the organic solar cells.
- The production of organic and perovskite solar cells has yet to be upscaled, which limits its availability. Therefore, to maximize the impact of organic and perovskite solar cells on SDG 7 (i.e., access of affordable, reliable, sustainable, and modern energy for all), priority should be on individual homes without electricity access to reach basic electricity access.

Introduction to solar power systems

Currently, many regions in the Global South lack access to affordable, reliable, sustainable, and modern energy, especially in remote areas[1]. Thus, many remote communities in the Global South are dependent on unstable energy sources or have no energy access at all[2]. This is because connecting remote areas to a central electricity grid is often too costly, requiring too many resources [3].

The lack in adequate access to energy cannot only be solved by strategies that enable traditional extension of centralized grid systems[4]. A promising way to provide remote areas in the Global South with stable energy access is through off-grid solutions[5] such as solar power systems (SPSs). The implementation of SPSs in remote communities can increase productivity, improve health, and generate employment, which leads to the empowerment and self-sufficiency of the community[6]. In this policy brief two SPSs will be covered: solar microgrids and solar home systems. Solar microgrids are small-scale electricity grids powered by photovoltaics (PV) panels. Solar home systems are energy systems powered by PV panels for individual households.

Despite the benefits that SPSs can bring to remote areas, some barriers have prevented SPSs from enabling large-scale access to energy. Lacking financial access of remote communities to SPSs is a recurring barrier to large-scale implementation[8,9], causing dependency on external actors. Additionally, a lack of agency, knowledge, and community participation can decrease the local communities' involvement in the implementation of SPS, which can potentially hinder the long-term sustainability of the system, as communities are left without necessary skills for operation and maintenance[9].

Type of solar cell	Organic Solar Cells (OSC)	Perovskite Solar Cells (PSC)	Conventional Solar Cells (CSC)
Efficiency*	19%	30%	20%
Weight in kg	0.5	0.5	20-30
Durability in years	5	1	25
Amount of lead in g per m^2	0	0.4	8.4
Circular	Yes	Partially	No
Able to connect to an electricity grid	Yes	Yes	Yes

* Amount of electricity generated per total amount of irradiance on the cell's surface, efficiency is based on measurements performed in laboratories

Figure 1: Overview of characteristics of OSC's & PSCs compared to conventional solar cells [11-13, 15, 21-26].

In addition, due to the remoteness of the areas, regular maintenance is another barrier[3]. Conventional solar cells lack a circular design, posing environmental issues and increasing maintenance for SPSs. It is often easier and more cost-efficient to replace a broken panel than to repair it[10].

Recent findings suggest that solar printing technologies (SPTs) such as organic solar cells (OSCs) and perovskite solar cells (PSCs) can help with the successful implementation of SPSs[11-13]. Printing technology has potential in producing cheaper, lighter, more circular, and more efficient solar cells compared to conventional solar panels (see figure 1). Thus, the application of printing technologies in SPSs in remote areas can potentially help in narrowing the gap between the Global South and North regarding access to affordable, reliable, sustainable, and modern energy (SDG 7)[14].

This policy brief explores the possible pathways for printing technologies for PV cells to enable an inclusive, sustainable, and large-scale implementation of SPSs in remote areas in the Global South, ultimately improving access to energy in these remote areas. First, it provides an overview of printing technologies for PV cells. Then, the brief presents different possible pathways in which SPT influences SPS implementation, from which conclusions and policy recommendations will be derived.

Solar printing technology explained

SPTs have large potential for powering SPSs in off-grid remote areas. For this, two SPTs have attracted significant attention from research and industry: organic solar cells (OSCs) and perovskite solar cells (PSCs). Because they might be developed for standalone use or in tandem applications, meaning they are combined with today's dominant silicon PV panels[15].

OSCs are made from carbon based small molecules or polymers and conductive inks[11]. This enables fast and low-impact production through printing layers of organic material on a flexible substrate. However, material cost and efficiency issues have persisted since interest increased in the early 2000s[16]. OSCs show high potential for low-power applications[11]. Its properties mean that research and industry is looking at applications for individual-level power generation such as portable electronics[17]. Moreover, OSCs are suitable for quickly fulfilling electricity needs for low-demand applications.

PSCs are made from perovskite materials that also enable them to be produced through printing manufacturing through similar processes as the OSCs. A more recent development, PSC research has progressed quickly over the past decade, resulting in a laboratory record of almost 30% energy efficiency (compared to 19% in OSCs)[18,19]. Although technical challenges such as durability exist, PSC properties and rapid development have drawn interest for larger scale application such as SPSs.

Challenges for SPTs do exist. First, the durability of SPTs is not up to par with conventional solar cells (figure 1), especially PSCs which have a very low durability of one year. Second, pilot projects of SPTs are lacking, although currently some have been initiated[20]. Third, PSCs contain a small amount of lead (figure 1), which increases environmental risks[13 21]. However, when comparing the different technologies, SPTs mostly perform equal or superior to conventional solar cells (figure 1; [11–13,15,21–26]).

A comparison of the costs per kWh of the different technologies is presented in Annex 2. If the durability of SPTs is increased through research, the price of a kWh becomes comparable to conventional solar cells. In addition, the costs of production of the SPTs are projected to be lower than the conventional solar cells, once this production is upscaled[27–29]. Currently, production costs of SPTs are higher than the conventional solar cells, as they are produced on a small scale[11 13]. It must be noted that these are all future projections, and therefore, subject to high levels of uncertainty.

To conclude, properties of the SPTs allow them to be produced locally and are easy to install, operate and maintain. Therefore, they have a lot of potential to power SPSs for off-grid remote areas in the Global South.

Exploring possible future pathways for SPS implementation

Through expert interviews and scientific literature, eight factors driving an inclusive, sustainable, and large-scale implementation of SPSs were identified (see Annex 1 for the definitions of all driving forces). To assess how these factors, influence the inclusivity, sustainability, and scalability of SPS implementation, four possible future pathways were explored. The pathways are distinguished by two overarching themes: (1) whether SPSs are financed and regulated by either private or public actors; and (2) if communities have access to ownership through either collaborative or individualistic structures. For a summary of the different pathways, see figure 2.

Annex 8 provides guidelines on how to use the analysis of the possible future pathways. This plan is meant for decisionmakers active in the implementation or operation and maintenance (O&M) of SPSs and introducing SPTs for remote electrification.

Next, for each pathway the most important outcomes will be presented.

Pathway A; Collaborative – Public initiative

In this pathway, governmental actors enable knowledge distribution and adaptable regulations through collaboration with local governments and assemblies, representing their respective communities. Through governmental subisidies and networks, remote communities can be involved in the implementation process of SPSs that would otherwise be economically unfeasible to reach. Governmental actors can set incentives to boost local research, production and implementation of SPTs, supporting faster implementation. The adaptability of regulations to local contexts ensures that these technologies meet the needs of the respective communities, increasing their social acceptance. Due to their user-friendliness, SPTs can be easily distributed through local collaboration and adapted to the communities' needs.

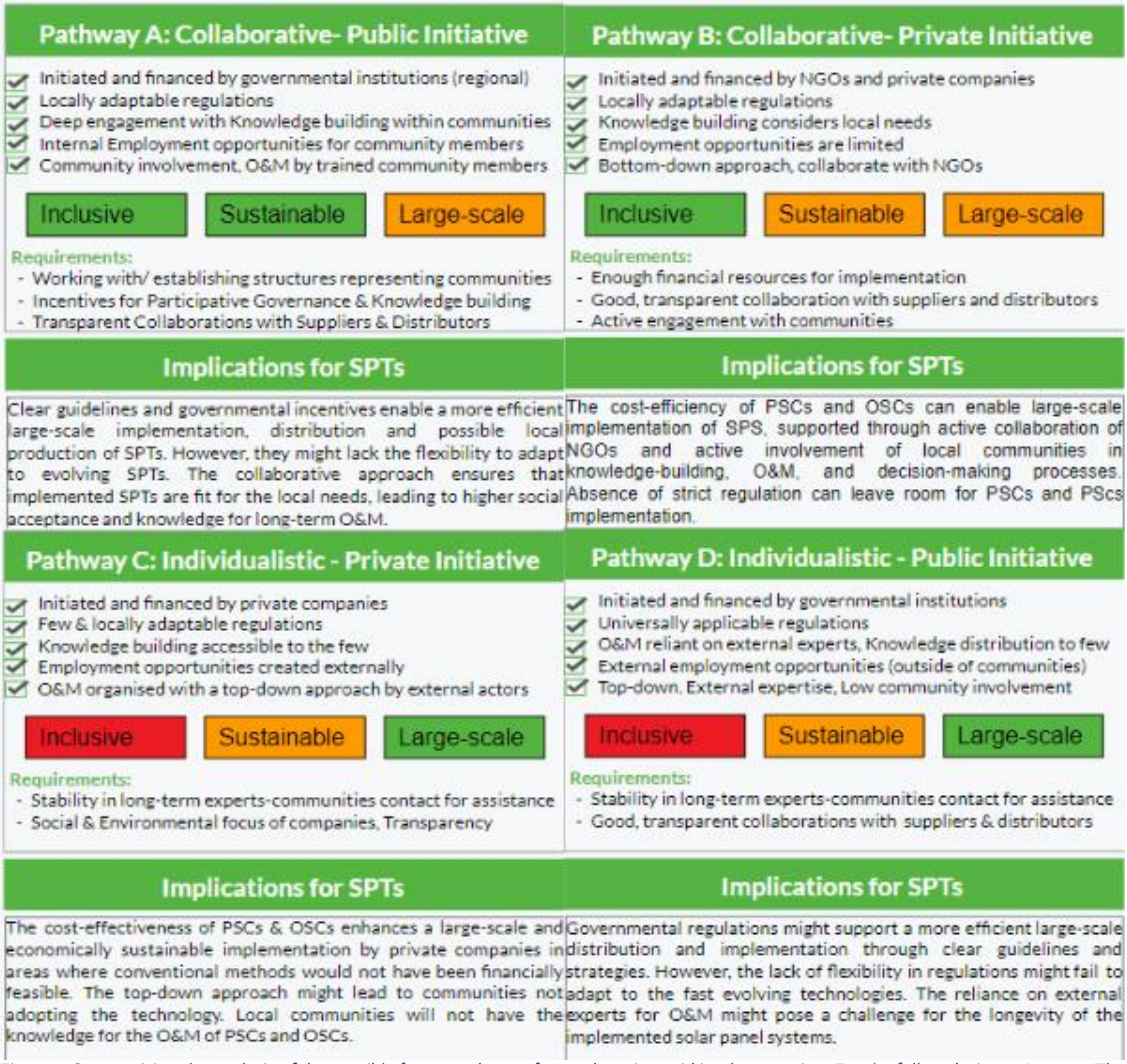

Figure 2: Summarizing the analysis of the possible future pathways for a solar microgrid implementation. For the full analysis see Annex 4. The different colours in figure 2 indicate the strengths and weaknesses for a sustainable, inclusive, and large-scale implementation for every specific pathway (see annex 1 for the definitions).

Pathway B; Collaborative – private initiative

In this pathway, engagement with the communities and knowledge building are seen as a priority during the implementation process of SPSs, which is initiated by or in close collaboration with NGOs. Combined with a bottom-up approach, where communities are involved in the decision-making process, it enhances a sense of ownership and community participation[30,31], ensuring long-term O&M by the communities.

Since NGOs are non-profit organizations and are partially funded by donors, this future pathway enables an SPS implementation in smaller communities. However, a large-scale implementation of SPSs remains a challenge, as reaching multiple smaller communities requires many resources[10]. Thus, this pathway is suitable for small-scale implementations, and for targeting specific remote communities.

SPTs can contribute to scaling up the implementation of SPSs in multiple smaller communities. Since the SPTs are easier to install, operate and maintain, knowledge building will be a less time-consuming process. In addition, the projected higher cost-efficiency will decrease the costs for SPSs implementation[11,13]. Having local experience, NGOs can ensure the involvement of relevant local distributors and stakeholders, raising the efficiency of SPTs implementation.

Pathway C; Individualistic – private initiative

Private companies initiate SPSs implementation when a feasible business plan for them exists, which is mostly the case in larger and more easily accessible off-grid communities, as smaller and more remote communities are often economically unfeasible to reach[10]. Companies should have a clear social and environmental focus in their business strategy and ensure transparency in the implementation process, to avoid possible exploitation of remote communities who might become dependent on their product.

SPTs can increase the economic feasibility in otherwise unfeasible communities, as SPTs are projected to be more cost-efficient than the conventional solar cells in production and distribution. Additionally, they require a lower level of expertise due to their user-friendliness. Thus, smaller communities might become economically feasible for private companies to implement an SPS[11,13]. Nevertheless, the communities will depend on the experts sent by the company for O&M, requiring a stable contact between them to provide enough long-term assistance[10].

Pathway D; Individualistic – public initiative

In this pathway, governmental actors initiate and guide the implementation process of SPSs through a top-down approach. This ensures clear regulations allowing for a more efficient large-scale implementation. However, the implementation is dependent on external expertise, which is why strong and transparent collaborations need to be established between the governmental actors, suppliers and distributors. To ensure long-term O&M, there needs to be regular contact between the external experts and respective communities.

In this pathway, the local research and production of SPTs can be chaneled by governmental incentives and available global funds. Through their network and available subsidies, governmental actors can reach otherwise economically unfeasible communities for electrification. Clear top-down regulations enable large-scale distribution, as suppliers have clear expectations on the demand and clear guidelines for the implementation process. However, the lack of adaptability from universal regulations might not be flexible enough to account for quickly evolving OSC and PSC technologies.

Conclusions

PSCs and OSCs offer a sustainable alternative to conventional solar panels due to their recyclability and OCS's biodegradability. Additionally, they are easier to install, operate and maintain, being suitable for an inclusive, sustainable, and large-scale electrification of remote communities. Furthermore, the production and implementation costs of these technologies are projected to decrease and become lower than those of conventional solar cells in the future [11] [13].

In many cases, a large-scale implementation of SPTs in the SPSs comes with costs which are too high for the initiators. To decrease the dependency on global supply chains, investments in research and development are needed to boost local production and research of SPTs. Creating incentives for local production and implementation can create momentum for governmental actors, NGOs, or private companies to invest in the implementation of SPSs and overcome the cost-barriers.

Inclusiveness is a pre-requisite for long-term sustainable implementation. Without ensuring sufficient knowledge distribution about the O&M and installation of solar cells among the community, communities engage less, lacking necessary skills and sense of ownership over the implemented technologies. This inhibits the longevity of the technologies, as their maintenance heavily relies on external experts, who often cannot ensure consistent visits to these hardly accessible remote communities. In addition, due to the low durability of the SPTs (OCSs in particular, see figure 1), regular maintenance to the SPTs is required. This highlights the importance of knowledge distribution within the community. To effectively reach remote communities, it is necessary to work with or establish local assemblies representing local communities. Lastly, experts suggest prioritizing communities without any access to electricity during the electrification process to address energy poverty and inequalities. By first focusing on the easily, possibly cheaper, and quickly implementable OSCs and solar home systems, affected remote areas are provided with immediate basic electrification. Once basic coverage is ensured and communities gain a better understanding of solar power technologies, more robust SPSs with higher electrification power can be implemented.

Policy Recommendations:

1) Policymakers must ensure knowledge distribution within and regular engagement with the communities, to ensure communities are capable of the long-term operation and maintenance of SPTs and SPSs. To reach communities, an establishment or collaboration with local assemblies is highly encouraged, as well as collaboration with local NGOs. Expertise in O&M of SPSs can be ensured through collaborations with relevant stakeholders. Clear and regular communication with the communities' representatives is highly recommended to increase sense of ownership and social acceptance of the technology.

2) Strong and transparent collaborations must be created between the initiators, suppliers, distributers, and the communities themselves. These collaborations must fit the regional needs and requirements of different printing technologies, while ensuring transparency and an inclusive approach. Suppliers should closely collaborate with local distributers and initiators to ensure an efficient and sustainable long-term implementation, while supporting local economies and providing expertise.

3) To create most valuable impact, remote areas without any access to energy should be prioritized in the face of a large-scale SPSs implementation. First, basic electrification through solar home systems (powered by SPTs) should be ensured. Once a basic large-scale electrification is reached, more advanced SPSs with energy distribution can be implemented. The understanding of solar cell technologies the communities have gained through the basic electrification allows for social acceptance and more efficient and easier implementation of advanced SPSs.

4) Policymakers are highly recommended to set financial and regulatory incentives to enable attractive opportunities for the production and implementation of SPTs in SPS. Furthermore, global funds and additional financial resources should become available for research, development, and implementation of SPTs. These funds can be essential to create momentum and attractive opportunities for governmental actors, NGOs, or the private sector to invest in the implementation of OCSs and PSCs in Solar Panel Systems to fight energy poverty. Furthermore, additional financial resources help decrease dependency on global supply-chains, channelling local production of SPTs, and locally creating valuable employment opportunities. To ensure expertise, collaborations with research institutes on SPTs are encouraged.

References

1. Tracking SDG7: The Energy Progress Report, 2022 – Analysis [Internet]. IEA. [cited 2022 Dec 16]. Available from: https://www.iea.org/reports/tracking-sdg7-the-energy-progress-report-2022
2. Almeshqab F, Ustun TS. Lessons learned from rural electrification initiatives in developing countries: Insights for technical, social, financial and public policy aspects. Renewable and Sustainable Energy Reviews. 2019 Mar 1;102:35–53.
3. Torero M. The Impact of Rural Electrification: Challenges and Ways Forward. Journal of Development Economics. 2015;23(HS):49–75.
4. PWC. Electricity beyond the grid: Accelerating access to sustainable power for all [Internet]. 2016. Available from: https://www.pwc.com/gx/en/energy-utilities-mining/pdf/electricity-beyond-grid.pdf
5. IRENA. Off-grid renewable energy solutions to expand electricity access: An opportunity not to be missed [Internet]. 2019. Available from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Off-grid_RE_Access_2019.pdf
6. APEC. Microgrids for Local Energy Supply to Remote Areas and Islands in APEC Region [Internet]. Muradov K, editor. 2012. Available from: https://www.apec.org/docs/default-source/Publications/2012/12/Microgrids-for-Local-Energy-Supply-to-Remote-Areas-and-Islands-in-APEC-Region/2012_ewg_microgrids-Formatted.pdf
7. Islami MS, Urmee T, Kumara INS. Developing a framework to increase solar photovoltaic microgrid penetration in the tropical region: A case study in Indonesia. Sustainable Energy Technologies and Assessments. 2021 Oct 1;47:101311.
8. Patel H, Chowdhury S. Review of technical and economic challenges for implementing rural microgrids in south africa. In: 2015 IEEE Eindhoven PowerTech. 2015. p. 1–6.
9. Daniel S, Shinde Lounsbury D, Pablo Carvallo J, Deshmukh R, Apt J, Kammen D. Renewable & Appropriate Energy Laboratory | Microgrids for Rural Electrification: A critical review of best practices based on seven case studies [Internet]. Available from: https://rael.berkeley.edu/publication/microgrids-for-rural-electrification-a-critical-review-of-best-practices-based-on-seven-case-studies/
10. Anonymous. Researcher working on solar microgrid implementation. Interview on Solar Power Systems implementation in remote areas. 2022.
11. Taylor A. Interview on Organic Solar Cells. 2022.
12. Di Vece M. Interview on printing applications for solar cells. 2022.
13. Anonymous. Manager of company researching perovskite solar cells. Interview on Perovskite Solar Cells. 2022.
14. Goal 7 | Ensure access to affordable, reliable, sustainable and modern energy for all [Internet]. [cited 2022 Dec 18]. Available from: https://sdgs.un.org/goals/goal7
15. Alves dos Santos SA, N. Torres JP, F. Fernandes CA, Marques Lameirinhas RA. The impact of aging of solar cells on the performance of photovoltaic panels. Energy Conversion and Management: X. 2021 Jun 1;10:100082.
16. Seri M, Mercuri F, Ruani G, Feng Y, Li M, Xu Z xiang, et al. Toward Real Setting Applications of Organic and Perovskite Solar Cells: A Comparative Review. Energy Technology. 2021 May 1;9.
17. Fukuda K, Yu K, Someya T. The Future of Flexible Organic Solar Cells. Advanced Energy Materials. 2020;10(25):2000765.
18. Li C, Gu X, Chen Z, Han X, Yu N, Wei Y, et al. Achieving Record-Efficiency Organic Solar Cells upon Tuning the Conformation of Solid Additives. J Am Chem Soc. 2022 Aug 17;144(32):14731–9.
19. Energie HZB für M und. World record again at HZB: Almost 30 % efficiency for next-generation tandem solar cells [Internet]. HZB. Available from: https://www.helmholtz-berlin.de/pubbin/news_seite?nid=23248;sprache=en;seitenid=
20. Colsmann A, Röhm H, Sprau C. Shining Light on Organic Solar Cells. Solar RRL. 2020;4(6):2000015.
21. Körte F, Wessendorf CD, Schnabel T, Herrmann M, Schröppel B, Stadelmann K, et al. Lead-binding biogenic polyelectrolyte multilayer coating for lead retention in perovskite solar cells. RSC Adv. 2022 Nov 29;12(53):34381–92.
22. Solar Panel Size Guide: How Big Is A Solar Panel? [Internet]. Unbound Solar. 2019 [cited 2022 Dec 17]. Available from: https://unboundsolar.com/blog/solar-panel-size-guide
23. Wirth H. Recent Facts about Photovoltaics in Germany [Internet]. Fraunhofer ISE; 2021. Available from: https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/recent-facts-about-photovoltaics-in-germany.pdf
24. Gambogi WJ. Progress in PV Material Durability Test Methodologies. In: 2022 IEEE 49th Photovoltaics Specialists Conference (PVSC). 2022. p. 0868–70.
25. Xu T, Luo Y, Wu S, Deng B, Chen S, Zhong Y, et al. High-Performance Semitransparent Organic Solar Cells: From Competing Indexes of Transparency and Efficiency Perspectives. Advanced Science. 2022;9(26):2202150.
26. King A. Lightweight, bendy, cheaper – the promise of organic solar panels | Research and Innovation [Internet]. Available from: https://ec.europa.eu/research-and-innovation/en/horizon-magazine/lightweight-bendy-cheaper-promise-organic-solar-panels
27. Mulligan CJ, Bilen C, Zhou X, Belcher WJ, Dastoor PC. Levelised cost of electricity for organic photovoltaics. Solar Energy Materials and Solar Cells. 2015 Feb 1;133:26–31.

28. Levelized cost of energy by technology [Internet]. Our World in Data. [cited 2022 Dec 20]. Available from: https://ourworldindata.org/grapher/levelized-cost-of-energy
29. Han GS, Gong OY, Kim HJ, Kwon N, Huh JS, Seo J, et al. Cutting-Edge Studies Toward Commercialization of Large Area Solution-Processed Perovskite Solar Cells. Advanced Materials Technologies. n/a(n/a):2201387.
30. Anonymous. Organization working with indigenous communities in Australia. Interview on Implementation of projects in remote indigenous community. 2022.
31. Nasir M. Interview on Solar Power Systems implementation in remote areas. 2022.
32. What is Project Sustainability? – proposalforNGOs [Internet]. Available from: https://proposalsforngos.com/what-is-project-sustainability/
33. Bocco G. Remoteness and remote places. A geographic perspective. Geoforum. 2016 Dec 1;77:178–81.
34. MTF. Data | Multi Tier Framework [Internet]. Available from: https://mtfenergyaccess.esmap.org/data-analysis
35. Don-Agor K. Interview on Solar Microgrid Implementation for Remote Communities. 2022.
36. Cobigo V, Martin L, Mcheimech R. Understanding Community. Canadian Journal of Disability Studies. 2016 Dec 27;5:181.
37. Suryani A. Interview on Solar Power Systems implementation in remote areas. 2022.
38. Alam Hossain Mondal Md, Kamp LM, Pachova NI. Drivers, barriers, and strategies for implementation of renewable energy technologies in rural areas in Bangladesh—An innovation system analysis. Energy Policy. 2010 Aug 1;38(8):4626–34.
39. Larrison C. A Comparison of Top-down and Bottom-up Community Development Interventions in Rural Mexico: Practical and Theoretical Implications for Community Development Programs. 2000 Apr 14;
40. Văn Công Chính B. Interview on Solar Power Systems implementation in remote areas. 2022.
41. Miles S. Interview on Solar Power Systems implementation in remote areas. 2022.
42. Burke P, Widnyana J, Anjum Z, Aisbett E, Resosudarmo B, Baldwin KGH. Overcoming barriers to solar and wind energy adoption in two Asian giants: India and Indonesia. Energy Policy. 2019;132(C):1216–28.
43. Balls JN, Fischer HW. Electricity-Centered Clientelism and the Contradictions of Private Solar Microgrids in India. Annals of the American Association of Geographers. 2019 Mar 4;109(2):465–75.
44. Asmus P, Lawrence M. Emerging Microgrid Business Models. In 2016. Available from: https://www.semanticscholar.org/paper/Emerging-Microgrid-Business-Models-Asmus-Lawrence/67052852b5b104d9e7f61daaa1b7220d74cdb39d

Annex 1: Definitions in the context of this paper

Solar printing technology (SPT)	Printed layers are assembled on substrates forming flexible solar cells. Two types of SPTs are Organic Solar Cells (OSC) and Perovskite Solar Cells (PSC). The material they are made from differs; OSCs are made of organic material such as carbon-based molecules or polymers and conductive inks[12], whereas PSCs are made of perovskite materials.
Sustainable implementation	The ability of local communities to continue the implementation of SPSs over a long-term time horizon. The longevity of the implementation can be determined through the communities' capacity to maintain and manage SPSs after the initiators have left. Its capacity can be determined by the following factors: (1) The financial capacity of the community; (2) The initiators' involvement after the implementation; (3) The resources needed after the implementation (e.g., for the maintenance)[32].
Inclusive implementation	Inclusive implementation of SPSs enhances the level of self-determination and community involvement in decision-making processes of local communities located in remote areas. The level of self-determination can be divided into the following categories: (1) sense of ownership; (2) knowledge-building; (3) community participation.
Large-scale implementation	SPSs enable affordable energy access for all communities located in remote areas where this is technically and financially feasible.
Remote areas	Remoteness can be defined in two dimensions. The absolute dimension relates to absolute variables such as distance and time. However, the second 'relative' dimension will be used for this policy brief. The relative dimension relates to the connectivity of a certain area to the supply of services, to basic infrastructure and to connection to the central electricity grid[33].
Energy access	Defined by the Multi-Tier Framework (see Annex 3) as minimum tier 1 electricity access, with the aim of tier 5 electricity access[34].
Public initiative	Action taken by any governmental actors and government-controlled institutions.
Private initiative	Action taken by any entities separate from the government. This includes private companies, Non-Governmental Organizations, and individuals.
Ownership	The level of responsibility and ability to act taken towards the implementation of SPSs in remote communities in the Global South. As ownership is maintained, it allows the community to achieve self-sufficiency.
Local assemblies	A representative group of local leaders, from different remote communities in the region they are representing, that aren't part of the government yet have a legal standing [30,35].
Communities	A group of people who engage with one another and are linked by similar experiences or traits, a sense of community, and frequently by proximity to one another[36].

Annex 2: price per kWh for the SPTs and conventional solar cells

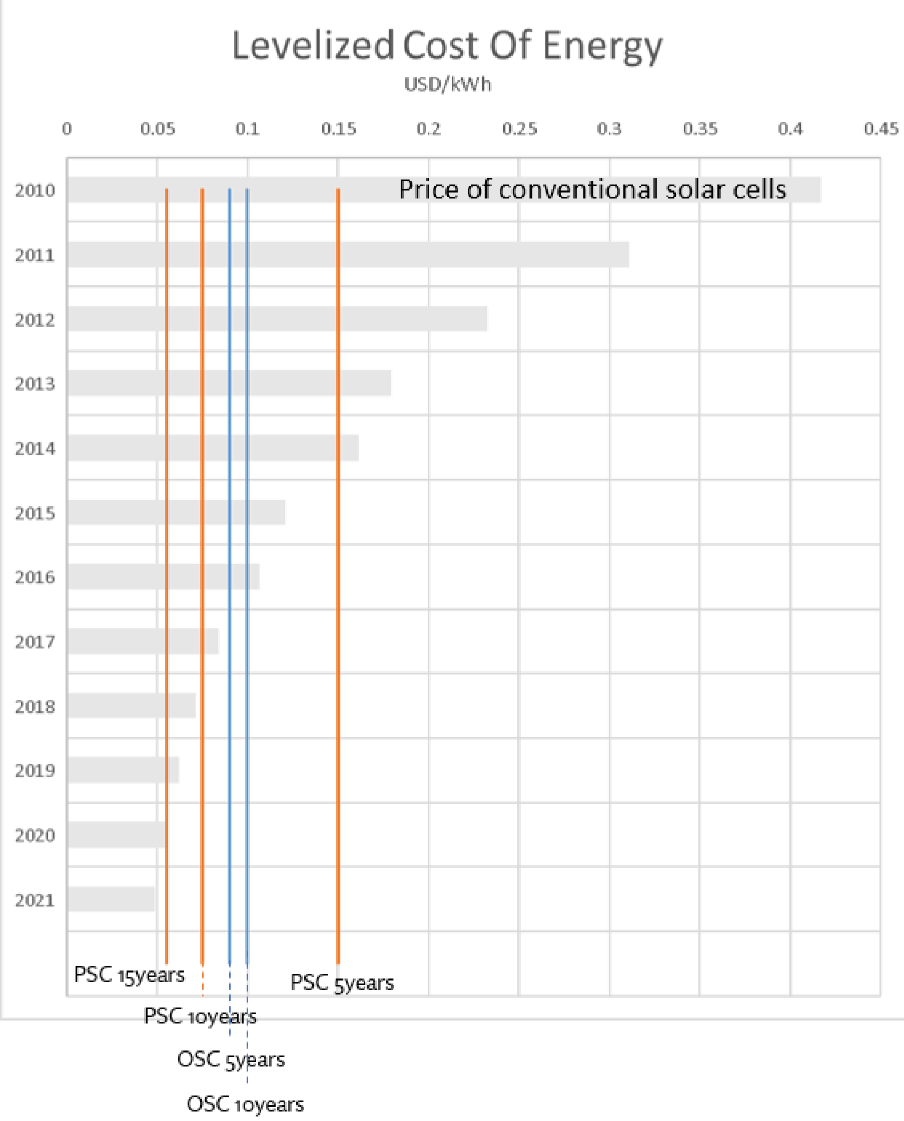

Figure 3: comparison of costs per kWh for SPTs and conventional solar cells

In the figure above the costs per kWh for the SPTs and conventional solar cells are presented. The costs per kWh depend on the durability of the solar cell. Therefore, in the figure different prices of OSCs and PSCs are presented for different durability's. It remains uncertain whether these durability's can be achieved as this is still under research [11,13]. In addition, the trend of the price per kWh of conventional solar cells is presented in the grey bars, as a comparison to the prices of the SPTs [27–29].

Annex 3: Multi-Tier Framework

ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3[b]	TIER 4	TIER 5
Capacity	Power capacity ratings (W or daily Wh)	Less than 3 W	At least 3 W	At least 50 W	At least 200 W	At least 800 W	At least 2 kW
		Less than 12 Wh	At least 12 Wh	At least 200 Wh	At least 1 kWh	At least 3.4 kWh	At least 8.2 kWh
	Services		Lighting of 1,000 lmhr per day	Electrical lighting, air circulation, television, and phone charging are possible			
Availability[a]	Daily Availability	Less than 4 hours	At least 4 hours		At least 8 hours	At least 16 hours	At least 23 hours
	Evening Availability	Less than 1 hour	At least 1 hour	At least 2 hours	At least 3 hours	At least 4 hours	
Reliability		More than 14 disruptions per week			At most 14 disruptions per week or At most 3 disruptions per week with total duration of more than 2 hours”	(> 3 to 14 disruptions / week) or ≤ 3 disruptions / week with > 2 hours of outage	At most 3 disruptions per week with total duration of less than 2 hours
Quality		Household experiences voltage problems that damage appliances				Voltage problems do not affect the use of desired appliances	
Affordability		Cost of a standard consumption package of 365 kWh per year is more than 5% of household income			Cost of a standard consumption package of 365 kWh per year is less than 5% of household income		
Formality		No bill payments made for the use of electricity				Bill is paid to the utility, prepaid card seller, or authorized representative	
Health and Safety		Serious or fatal accidents due to electricity connection				Absence of past accidents	

Figure 4: Multi-Tier Framework used to indicate levels of energy access [34]

To indicate the level of access to electricity, the Multi-Tier Framework is used. In this model, different tiers indicate different levels of energy access[34]. This policy brief illustrates the need for remote communities to get out from tier 0 to reach tier 1 or higher, as is shown in the framework above.

Annex 4: Research Question

What are possible pathways for solar printing technology to enable inclusive, sustainable, large-scale implementation of solar power systems in remote areas in the Global South, ultimately improving access to energy in these remote areas?

Annex 5.1 Driving forces

Driving forces for an inclusive, sustainable and large-scale implementation of SPSs. Orange indicates five different themes within the driving forces.

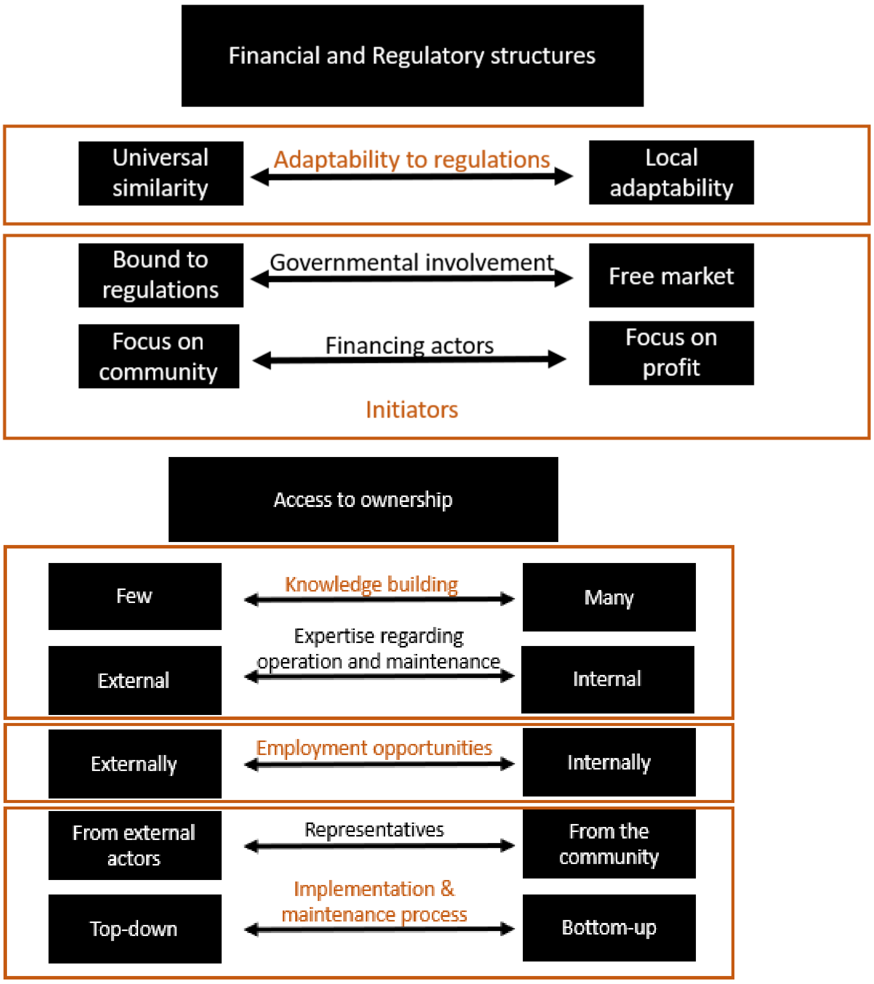

Figure 5: Driving Forces

Annex 5.2 Definitions of the driving forces

1. Initiators

The implementation of SPSs in remote communities relies heavily on the actors who initiated and financed it. Inherently, the involvement of the government in the implementation is ever-present[35]. However, governmental involvement in the implementation is limited to the extent of by whom it is initiated. Government-initiated implementation can lead to an implementation more bound by regulations. Whereas with less governmental involvement, SPS implementation is initiated by private actors in a freer market, resulting in less governmental intervention and regulations.

Moreover, financing actors of SPS implementation influence the possible pathways of the implementation. Actors that focus on the community (e.g., NGOs) allow for a more inclusive approach as it considers the needs of the community and. On the other hand, financing that focuses on profit (e.g., private companies), only initiate implementation when a feasible business model exists. This can enhance a large-scale implementation[10]. However, the upscaling of SPS implementation can only happen within an area that has potential feasible business model. Thus, in this case, small communities where energy access is lacking but often do not possess a feasible business model are often passed over[10].

2. Adaptability to regulations

Universally applicable regulations take on a general approach to the implementation[10], which enable faster and more efficient implementation processes. However, this form of regulations risks not meeting the more specific needs of the communities. On the other hand, local adaptability refers to how the regulations allow an implementation that tailors to the needs of the communities, thus ensuring inclusive implementation[37]. However, adapting regulations to different contexts of the communities can be time intensive, which can hinder the possibility of large-scale implementation[10].

3. Knowledge-building

Knowledge on SPSs is critical for the community to be able to implement, operate, maintain, and benefit from SPS[38]. The number of community members that engage with the implemented SPSs can influence the long-term sustainability of it. High involvement of community members in knowledge-building can enhance community agency on the implementation, whereas few involvements of the locals can limit the extent to which SPSs operate [30,31,35,37].

To achieve an inclusive implementation of SPSs in remote areas, communities need to be provided with knowledge and information in order to reach a certain expertise regarding O&M of SPSs[30,31,35]. It emphasises the community's dependency on SPS experts. These experts are either externally or internally employed. External experts, who already possess the necessary knowledge on SPS, are sent to the communities to distribute the knowledge and information to the communities. On the other hand, internal experts come from the community itself through sufficient knowledge-building, where it will gain first-hand knowledge by the initiators before disseminating it to the community[30,35].

4. **Employment opportunities**

As the implementation of SPSs is in place, its regular maintenance is critical to ensure longevity. This leads to the creation of employment opportunities to accommodate the O&M of SPSs[11]. These opportunities are available within and outside the community, depending on the terms of the initiators and the level of community involvement. In cases where employment opportunities are available externally, SPS experts are sent to the community to install, operate, and maintain the SPSs without any involvement with the community. Such cases can undermine the self-sufficiency of the community, risking the feasibility of long-term implementation[30]. In contrast, employment opportunities that exist internally within the community allows a more inclusive approach as it involves the community to actively engage in the O&M of the SPS, thus enhancing community agency and self-sufficiency [35].

5. **Implementation and maintenance process**

A top-down approach shapes the implementation of SPSs in remote areas, as decision-makers barely involve the local communities [10] [39]. A top-down approach can limit an inclusive implementation, although it allows for a faster and more efficient implementation[10]. On the other hand, a bottom-up approach calls for the involvement of the community in decision-making processes, enabling an inclusive implementation that fulfills the needs of the community[11,30,35]. In this approach, the initiators collaborate with the community to establish a community-oriented approach, providing technical support to the community rather than leadership, which ensures inclusive implementation[30]. A bottom-up approach can be more time-intensive, causing for a slower and less efficient implementation [10].

Annex 6: Methodology

This policy brief is based on the analysis of related literature and expert interviews which is then used to identify barriers to inclusive, sustainable, and large-scale implementation of SPSs in remote areas in the Global South. In addition, interviews with experts will be used to verify information found in the literature and in the pathway analysis. The pathway analysis is where the pathways of SPT applications and limitations are built based on information found in the literature and expert interviews. These pathways draw upon how SPTs can be used to enable inclusive, sustainable, and large-scale implementation of SPSs in remote communities of the Global South. Policy recommendations are developed based on the opportunities and challenges observed in these pathways.

Annex 7: Interviews

Name of Expert	Title & affiliation	Interview on
Amalia Suryani	Researcher in energy access and rural development	Solar Power Systems implementation in remote areas
Amelia Taylor	CEO Power Bloom Solar, Inc.	Organic Solar Cells
Bùi Văn Công Chính	Director of First Solar Vietnam Manufacturing Co., LTD	Implications of Solar Power Systems implementation in remote areas
Marcel di Vece	Researcher in printing applications for solar cells	Printing applications for solar cells
Mashood Nasir	Researcher in Solar Power Systems	Solar Power Systems implementation in remote areas
Samuel Miles	Researcher in Solar Power Systems	Solar Power Systems implementation in remote areas
Kofi Don-Agor	President of Climate Communications and Local Governance (CCLG-Africa), working under the Public Affairs department of Parliament of Ghana	Solar Power Systems implementation for remote communities
Anonymous	Researcher in Solar Power Systems	Solar Power Systems implementation in remote areas

Anonymous	Manager of a company researching Perovskite Solar Cells	Perovskite Solar Cells
Anonymous	Organization working with indigenous communities in Australia	Implementation of projects in remote indigenous community

Annex 8: Guidelines on how to use the analysis of future pathways

In this Annex, guidelines on how to use the analysis for possible future pathways are presented. It is meant for decisionmakers active in the implementation or O&M of SPSs and introducing SPTs for remote electrification.

1. Define which future pathway is applicable to the communities targeted by your implementation process of SPSs and SPTs. Do this by asking the following questions:
    a. Is the SPSs implementation going to be **financed and regulated** by public or private actors?
    b. Will the communities be involved through an **individualistic or collaborative approach**?
    c. Which pathway best fits your **context and available resources** for implementation?
2. The different colours in figure 2 indicate the strengths and weaknesses for a sustainable, inclusive, and large-scale implementation for every specific pathway (see annex 1 for the definitions). Assess the **main challenges and trade-offs in your future pathway**, adapting them to your context.
3. Each pathway contains **requirements** to make an inclusive, sustainable, and large-scale implementation successful. Assess what these requirements entail for your future pathway.
4. For each pathway the **potential and challenges in implementing SPTs** are described. Assess in which way these technologies can enhance an inclusive sustainable and large-scale implementation of an SPS in your pathway and what needs to be considered.
5. For additional information, see Annex 9. It contains the full analysis of the future pathways, including: a description per pathway; the implications for an inclusive, sustainable and large-scale implementation per pathway; implications for SPTs per pathway. In addition, the analysis is organised per driving force.

Annex 9: Analysis of future pathways

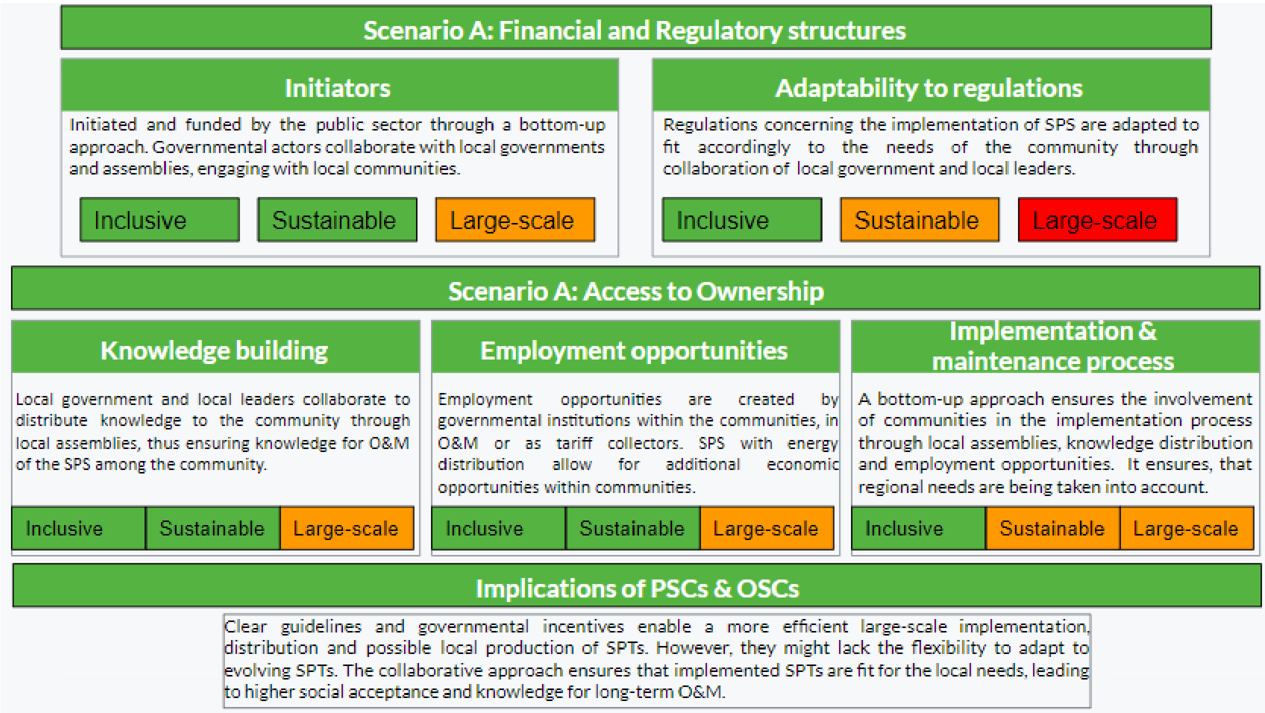

Figure 6: Overview of Pathway A

Pathway A: Collaboration - Public Initiative

Financial and Regulatory structures

1. *Initiators*

Description

SPSs are initiated and funded by the public sector, while the involvement of the private sector remains limited due to uncertain cost recovery and restrictive regulations[10,11,37]. Governmental actors can make use of available resources and partnerships, such as existing legal structures, local governments, research institutions or consultancy firms[10,11,37].

Implications for an inclusive, sustainable, and large-scale implementation

Even though government-initiated projects can reduce the costly implementation of SPSs through available subsidies and provide better accessibility to the community by working with local governments and representatives[13], governments in the Global South often have limited funds for the implementation of frontier technologies in SPSs, thus Global Funds might be necessary to ensure a sustainable large-scale implementation and boost local production and research of the frontier technologies[40,41]. Depicting the collaborative nature of the public initiatives, the central government collaborates with the local governments and local assemblies (representing leaders of the remote communities) in the implementation. Anything that has to do with the local community should pass through local assemblies and the local government before moving towards the central government[35]. Clear communication to local assemblies about the benefits and challenges of the implementation to the community leaders in the local assemblies needs to be ensured to ensure the social acceptance of the technologies. Local assemblies might provide valuable resources and experts for knowledge transfer and implementation, as they know the needs of their communities best. Thus, partnerships between local community leaders and local government help ensure inclusiveness and long-term sustainability through knowledge transfer and an engagement of the communities in the process. This collaborative approach in large-scale implementation helps ensure local adaptability of the implementation to different communities' needs, however it also requires time- and labor-intensive resources, which might hinder a large-scale implementation[30].

2. *Adapta*bility of regulations

Description

Collaboration between central and local governments and local communities enables regulations concerning the implementation of SPSs to be adapted according to the needs of the community. These collaborations might help to better determine how many panels would be needed and what already existing resources could be used for distribution and instalment.

Implications for an inclusive, sustainable, and large-scale implementation

The local adaptability of regulations ensures that differences in the needs of affected communities can be considered, making every implemented SPS suitable for the local circumstances and more prone to be adopted by the community. This ensures inclusivity and stability of implemented SPSs during large-scale implementation. However, ensuring local adaptability of regulations requires more time and resources for the implementation process, as collaborations and consulting are needed, thus slowing down a large-scale implementation[10].

Implications of SPTs for financial and regulatory structures

Governmental involvement supports a large-scale implementation of OSCs and PSCs, as it can provide clear guidelines and incentives for implementation[10]. A pre-requisite of close collaboration is clear communication, where community leaders are well informed about the process, benefits, and challenges of the implementation through their local assemblies. To decrease dependency on global supply chains, governments can set incentives for local research and production of OSCs and PSCs. Additionally, close collaborations with global leaders on OSC and PSC research might be helpful, as well as using global funds as additional resources to support research, production and implementation of these technologies[35].

3. *Knowledge-building*

Description

Knowledge distribution is ensured by local governments collaborating with local assemblies, who then can transfer the knowledge and skills to their respective communities, using already existing frameworks and resources[35]. External experts can be employed, but always in close collaboration with the local assemblies and communities.

Implications for an inclusive, sustainable, and large-scale implementation

The knowledge and information should always go through local assemblies, before being circulated to the community by the educators[30]. The knowledge-building[41], reaches the whole community to encourage active involvement in the implementation of SPSs or, at least, it should be feasible to educate enough community members for them to know who to contact and how to identify problems that arise. This ensures inclusivity and long-term sustainability, however, might pose challenges to large-scale implementation due to the time-intensive process.

4. *Employment opportunities*

Description

Community engagement is further achieved through owning and sharing resources, employment opportunities are created within the respective communities[31]. Governmental institutions can employ community members for implementation, operation, maintenance, or jobs such as tariff collectors. Microentrepreneurs are emerging as SPSs enable the community to create economic opportunities in the case of energy redistribution in advanced microgrids.

Implications for an inclusive, sustainable, and large-scale implementation

Creating employment opportunities for community members increases their sense of ownership and motivation to engage with the technologies and in the implementation process. Thus, inclusivity and long-term sustainability can be ensured. The higher motivation of communities to engage in the process can enable large-scale implementation. However, distributing jobs among different communities might be time- and resource-intensive.

5. Implementation process

Description

The implementation process is characterized by a bottom-up approach and deep engagement with the communities. Communities are enabled to actively participate in the process, mainly through local assemblies and community leaders, but also through employment opportunities created. Governmental actors can make use of the local assemblies' resources, to reach communities, distribute knowledge and for communication.

Implications for an inclusive, sustainable, and large-scale implementation

The bottom-up approach ensures inclusivity and creates a strong sense of ownership, leading to a wider social acceptance of the technologies within the communities. Knowledge distribution and efficient communication with the communities ensure long-term sustainability. Clear governmental guidelines and frameworks for the process and how to work with local assemblies can enable a large-scale implementation, however, keeping in mind that the bottom-up approach might slow the process down[35].

Implications of SPTs for access to ownership

Depicting the collaborative nature of the pathway, the government and the community can collaborate to gain new knowledge on the implementation and the utilization of the printing technologies[10]. Application of printing technology in SPSs allows the community to pursue jobs involved in SPS maintenance as both perovskite and organic solar panels are easier to install, to operate, and to repair, leading to less dependency on external experts. Governmental actors can use their networks and incentives to enable a large-scale implementation and boost local production and research of SPTs. As the printing technologies are created by private companies, the government must be able to create a clear and long-term strategies for transparent partnerships with the supplying companies. Local assemblies might provide valuable networks to collaborate with local distributors, boosting local economy and enabling an implementation of SPTs that is fit for the regional ,

Pathway B: Collaboration - Private Initiative

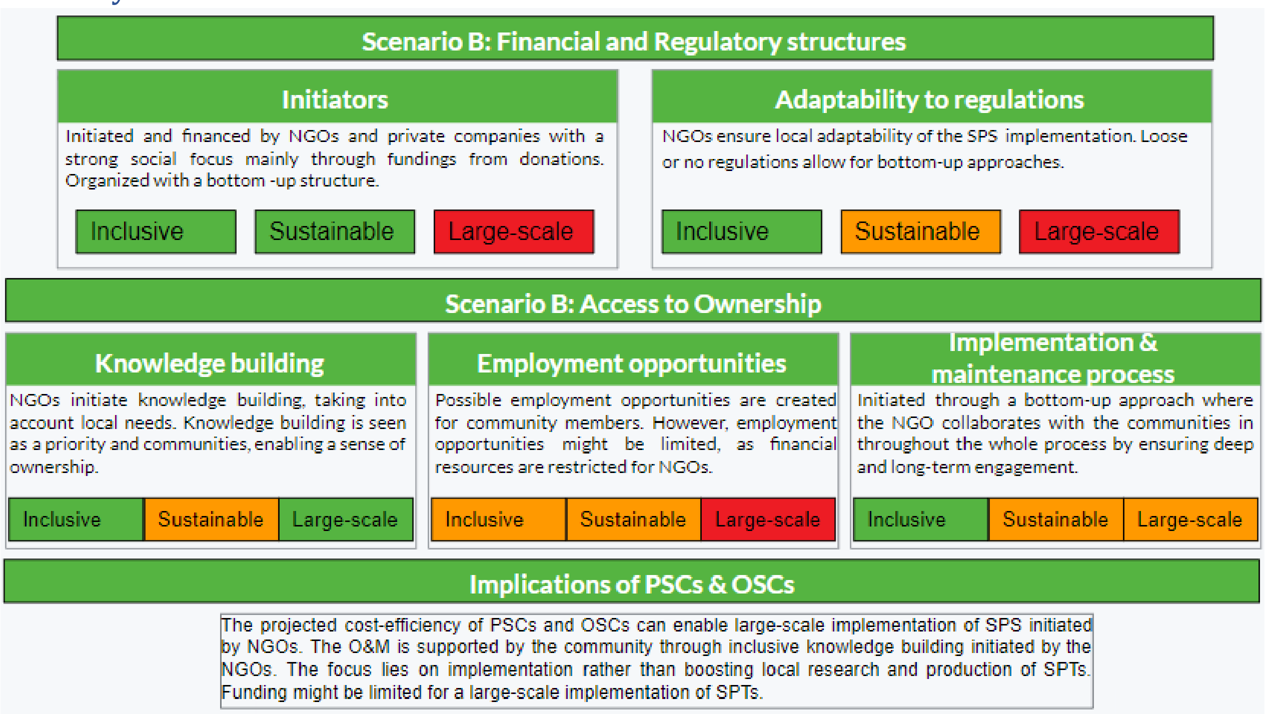

Figure 7: Overview of Pathway B

Financial and Regulatory structures

1. *Initiators*

Description

NGOs initiate SPS projects or are at the forefront of their implementation. Companies with a strong social and environmental focus are sometimes involved. Funding comes from donations and funds available to NGOs, which are used not only for the implementation, but also for research that can help local production[35,40]. The public sector sometimes contributes financially but is not involved in the implementation nor does it strictly regulate the process, leaving room for bottom-up approaches[30].

Implications for an inclusive, sustainable, and large-scale implementation

The local NGOs can deeply engage with the local population where the SPSs are being implemented, ensuring that knowledge is distributed among the community. Community participation is enhanced and maintenance, operation, and management of the SPSs is done through community involvement. Scalability issues might arise because funding can be difficult to acquire and depends on (geo)political developments. Scarce funding might drive initiators to deprioritize community engagement and local production, thus hindering large-scale implementation.

2. *Adaptability of regulations*

Description

NGOs ensure local adaptability of SPSs implementation. Loose or no regulations allow for bottom-up approaches. Regulation on SPSs implementation is unspecific and is mainly derived from other laws. There is a need for community engagement to determine the technical and social properties of a project, something that NGOs will prioritize doing.

Implications for an inclusive, sustainable, and large-scale implementation

As regulations concerning SPSs implementation are circling around the needs of the community, it can support inclusivity thus enabling a long-term implementation of the system. Nevertheless, adapting regulations to local context can be time-intensive and vague, which can obstruct the upscaling implementation of SPSs.

Implications for SPTs for financial and regulatory structures

OSCs and PSCs can contribute to the scalability of donor funded SPSs, since they are expected to significantly drive down the energy costs. Although this might leave more time for community engagement, in this pathway this is already the norm. NGO-led implementation and the absence of strict regulation gives space to test out this new technology[13].

Access to ownership

3. *Knowledge building*

Description

NGOs take an active role in knowledge building, taking into account cultural and local wants and needs[30]. Knowledge-building is seen as priority, and it is clear to local communities what the benefits are. This does not mean that every person in a community learns to maintain an SPS, but that there are enough people who can identify issues and know where to ask for help.

Implications for an inclusive, sustainable, and large-scale implementation

Knowledge building in the collaborative-private way can increase community agency. In this pathway, deep engagement with community members makes the process more inclusive and can increase longevity of the SPSs. With profit being secondary to sustainability, knowledge-building serves to maintain the SPSs on the long term and might improve circularity. Community members take agency of redundant PV technology, although the success of this depends on the government incentives to return these materials. Large scale implementation might be improved only on the long term. Distributed ownership and agency decrease the need for repeated SPSs implementation, but it does not change the limits to large-scale implementation immediately[31].

4. *Employment opportunities*

Description

It is challenging to create employment opportunities through NGO-initiated SPSs. The involvement of companies with a strong social and sustainable profile might increase this. Cooperative financial strategies are a logical thing to pursue in this pathway, since they require high engagement and learning from the community and are still possible with less profit or funding[10].

Implications for an inclusive, sustainable, and large-scale implementation

The employment opportunities are mostly limited to knowledge sharing and cooperation on a financial strategy. Large-scale implementation is not accelerated but also not hindered. Inclusive practices are the priority. Sustainability is at risk because the circularity of the technology is not always ensured. Upfront costs for collection materials are not easily met.

5. *Implementation and maintenance process*

Description

NGO-initiated implementation is operationalised through a bottom-down approach, as it collaborates with the community by involving them in decision-making process. The collaboration can contribute to increasing the local adaptability of SPSs implementation and increase community agency. Furthermore, regular inspection by the NGOs is done in the community, creating a close relationship with the community[10]. Challenges of accessibility to the community can be removed as NGOs utilize its pre-existing network to enhance SPSs implementation[30] and keep close contact with the community[10].

Implications for an inclusive, sustainable, and large-scale implementation

As the communities are actively involved in decision-making processes of SPSs implementation, it will enhance self-determination and community agency thus enabling a sustainable implementation. However, a collective decision-making process can potentially hinder large-scale implementation as it can be labour and time intensive[10].

Implications for SPTs for access to ownership

OSCs are suitable for fulfilling the community's energy demand due to its modular design[11] thus creating opportunity for the upscaling of SPSs implementation. In addition, NGO collaboration with the community ensures a locally adaptable implementation through distributed knowledge building and involving the community in decision-making processes. The community's knowledge on SPTs, in addition to the user friendliness of SPTs, can contribute to a long-term implementation and maintenance of SPS.

Pathway C: Individualistic – Private Initiative

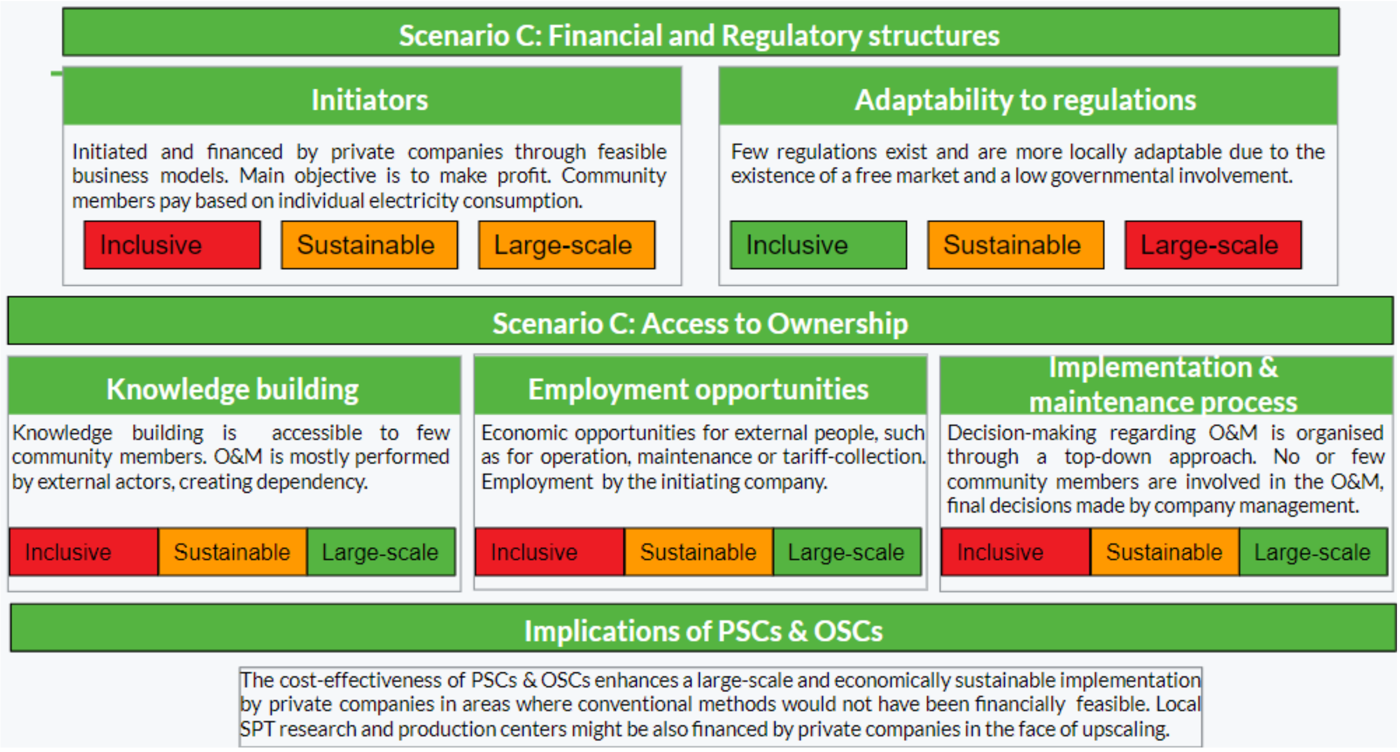

Figure 8: Overview of Pathway C

Financial and Regulatory structures

1. *Initiators*

Description

In this pathway, the implementation of SPSs in remote areas is initiated and financed by private companies. There is no focus on collaboration with NGOs, since NGOs tend to work in a more collaborative manner. The SPSs are financed through business models with a profit incentive, meaning this pathway operates under free market conditions. The implementation of SPSs only occurs in areas where business would be feasible. Individuals using energy generated by the SPSs pay to the private company based on their consumption, while funds by the NGOs can be used for further research on SPSs, including how to enable local production[35,40]. Prices per kWh are based on the supply and demand within the different local communities[41].

Implications for an inclusive, sustainable, and large-scale implementation

The implementation of SPSs initiated by private companies through feasible business models enhances an economically sustainable and large-scale implementation. This is because, when a feasible business model for SPSs exists, it can be scaled up to other remote areas in which this is also the case[10].

However, large-scale implementation stops in areas where a feasible business model does not exist. Therefore, it would not promote an inclusive implementation. In remote areas with relatively small communities, it is unlikely to have a feasible business model for an SPS, while these are often areas where access to energy is lacking the most. On top of that, in areas where a feasible business model does exist, only people able to pay for energy would be included[10].

2. *Adaptability of regulations*

Description

In this pathway the implementation is mainly initiated by private companies within a (relatively) free market, this will most likely mean that few regulations exist and are more locally adaptable, as usually under a free-market companies are less bound to regulations. In addition, in some countries (e.g., Indonesia) only governments are allowed to provide energy access, the fact that in this pathway private companies are able to implement SPSs means that probably less regulations exists[10,41].

Implications for an inclusive, sustainable, and large-scale implementation

A high local adaptability to regulations means that the implementation of SPSs will become more tailored to the needs of different communities[10,11]. This will enhance an inclusive implementation since the needs of the communities are more specifically met. However, adapting to regulations in different contexts is time-intensive, which will make it more difficult to scale up[10].

Implications of SPTs for financial and regulatory structures

SPTs can partially contribute to enhancing an inclusive, sustainable, and large-scale implementation. In this pathway the main constraint is the cost. Feasible business models do not exist due to (1) the remoteness of areas lacking energy access, (2) the vast geographical distribution of communities living there and (3) the small numbers of people these communities consist of. However, SPTs' potential high cost-efficiency will lower the entry barrier for companies to construct SPSs in areas where conventional methods would not have been financially feasible. Therefore, more people lacking energy access are reached, ultimately enhancing an inclusive economically sustainable and large-scale implementation. In addition, an environmentally sustainable implementation is enhanced through the circularity of these printing applications. Also, the inclusive implementation is further enhanced due to the SPTs' easy deployment[11,13].

Due to the different needs of communities, it will be difficult to implement these technologies on a larger scale. Although, since the quality of the implementation will be better due to the locally adaptable regulations, it will enhance long-term sustainability of the technologies. But, as these technologies are already more adaptable to the needs of different communities due to the user-friendliness and easy deployment of these technologies it might be more beneficial to focus more on universal regulations, which promotes a large-scale implementation[13].

Access to ownership

3. *Knowledge building*

Description

Maintenance of the SPSs is initiated by the private company, which is paid for through the yields of this same company. The company will send their experts to install the SPSs, potentially training a small number of representatives from the local community. Maintenance is performed by experts hired by the company. Since the company benefits from an efficient approach, both the installation and maintenance of the SPSs will occur efficiently and effectively. However, this decreases the sense of ownership and participation of the local community[10].

Implications for an inclusive, sustainable, and large-scale implementation

Therefore, there is less focus for knowledge within the community. This has negative implications for inclusive implementation, as a successful uptake of the SPSs within the community requires a deep understanding among community members[35]. In addition, when community members are not involved in the maintenance of SPSs, communication from the community when maintenance needs can be lacking. This has further negative implications for an inclusive implementation but also negatively affects the long-term sustainability of the SPS.

4. *Employment opportunities*

Description

In this pathway, economic opportunities will be mainly external as the SPS are implemented with a top-down approach where operation and maintenance are mostly externally organised. For example, tariff collectors will be people hired by the private company externally.

Implications for an inclusive, sustainable, and large-scale implementation

When jobs are created due to SPS implementation are spent externally, this will lower the levels of community participation and may not be inclusive[10]. A large-scale implementation can be enhanced when an operator maintains multiple SPSs, which increases the efficiency. However, high transport cost due to the remoteness of these areas can hinder external experts from traveling to the communities, thus, maintenance performed by people from the communities themselves might be more beneficial for a large-scale implementation.

5. Implementation process

Description

Decision-making within the implementation process is performed through a top-down approach, 'top' being management of private companies. When the community itself is involved in the decision-making process, a small number of representatives will be chosen to participate. However, final decisions will be made by the private companies' management.

Implications for an inclusive, sustainable, and large-scale implementation

When communities are barely involved in the decision-making process during the implementation of SPSs, it will decrease their sense of ownership and community participation[10,31,35]. Therefore, this will have negative implications for an inclusive implementation. However, when decisions are made more centrally, it will enhance a large-scale implementation, since decisions can be extrapolated to different communities.

Implications of* SPTs *for access to ownership

When technologies are implemented in a top-down approach as described above, they might not be adopted by the local communities. This could cause vandalism, which is already a problem in some communities[13]. On top of that, when these technologies require maintenance, the communities will not have the knowledge required to maintain the SPTs. However, one of the bigger advantages of these technologies is that they are relatively easy to operate. Therefore, properly training community members for O&M may be cheaper than having experts travel to different remote communities[13].

Pathway D: Individualistic – Public Initiative

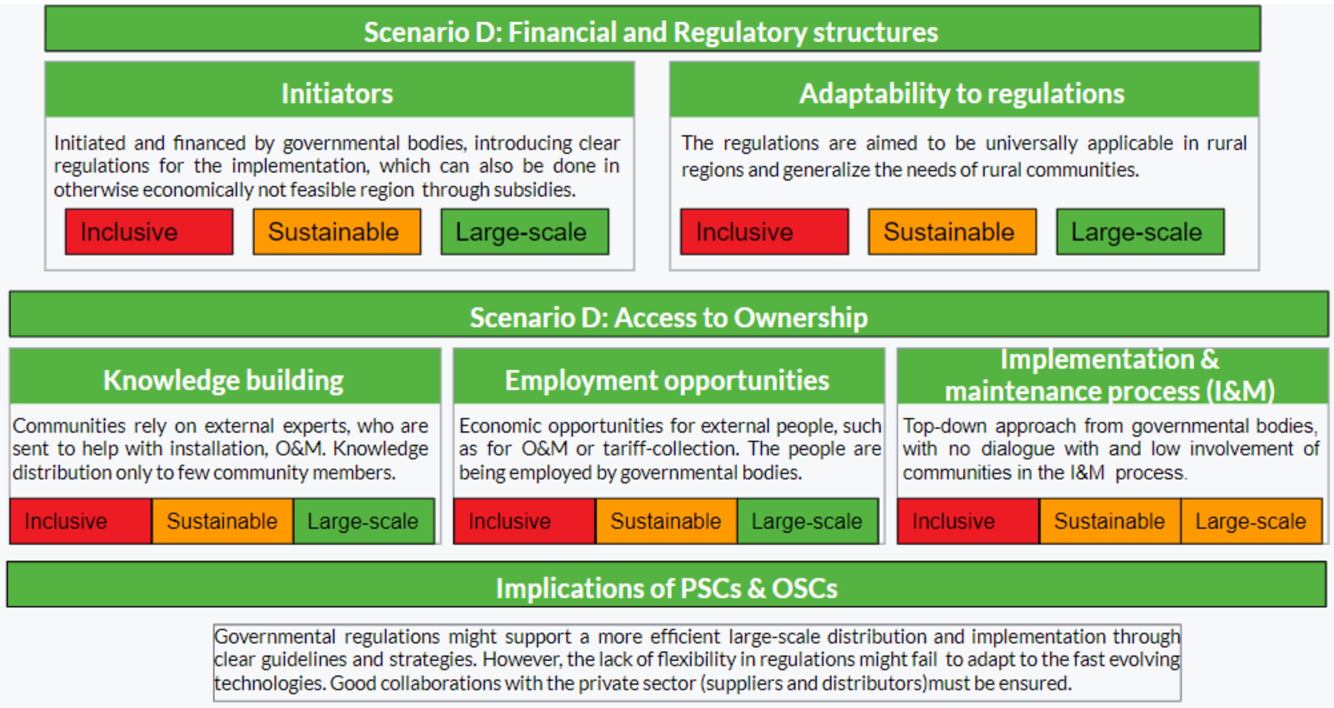

Figure 9: Overview of Pathway D

Financial and Regulatory structures

1. Initiators

Description

In this pathway, the implementation of SPSs in remote areas is initiated and subsidized by the public sector. Governmental bodies introduce clear regulations and measures for the implementation of the technologies in a top-down approach, thus, without thorough collaboration with local representatives. In many countries in the Global South, governments may need additional financial support from global funds to ensure an efficient large-scale implementation and further research and development in the local production of solar panels. Governments will implement SPSs in areas that may not be profitable to electrify. The main limitation to the implementation of SPSs in these areas would be cost. This is where a government can step in by providing subsidies to bridge the gap existing in the costs.

Implications for an inclusive, sustainable, and large-scale implementation
The level of governmental involvement is high, leading to stricter regulations which ensure clear guidance of the implementation process. As there is no time- and labor-intensive engagement with the remote communities, a large-scale implementation of the technology is possible in an efficient and relatively fast way, promising fast solutions for communities without energy[10,37]. However, there is less room for self-determination and bottom-up initiatives in the implementation process[10,35]. The individualistic approach might, thus, misunderstand the needs of local communities, leading to a low sense of ownership among communities. Without a sense of ownership, communities might feel the technologies are being imposed on them[30,31,35]. As a result, they might not see the benefits of the technologies to their full potential and lack motivation to maintain and operate them themselves[10,31,35]. Thus, long-term sustainability of the SPSs might be inhibited.

2. *Adaptability of regulations*

Description
The regulations from the governmental bodies would be universally applicable to remote regions and generalize the needs of remote communities.

Implications for an inclusive, sustainable, and large-scale implementation
Universally applicable regulations allow for faster and more efficient implementation processes in the face of a large-scale implementation[10]. However, they do not take the specificalities of different communities into account, being more prone to fail meeting the needs of the communities affected[10,35].

Implications of SPTs *for financial and regulatory structures*
Governments can set incentives for the local production, research, and implementation of SPTs. As the OSCs and PSCs come from the private sector, the policy-making bodies have to create a clear and long-term ensuring transparent collaborations with supplying companies and the distribution network to ensure a successful and sustainable implementation[11]. The involvement of governmental bodies can pose a challenge for collaboration with technology-supplying companies, as the technologies evolve quickly and regulations have to adapt accordingly, beyond election cycles[11]. However, clear regulations can also ensure more efficient guidance in large-scale implementation, defining clear guidelines and roles for the actors involved (technology suppliers, distribution networks, governmental bodies and possibly the communities)[10]. Universally applicable regulations make the production and distribution process of the panels easier, as technology suppliers have clear expectations and can supply in bigger amounts, without the need to adapt to local needs. However, the lack of understanding of local communities' needs might also lead to under- or over-supplying of solar panels per community.

Access to ownership

3. *Knowledge building*

Description
The SPSs initiation is supported by external experts sent to the communities to install the SPSs. External experts ensure efficiency, however, increase the dependency of the communities on external knowledge for operation and maintenance of SPSs. Training is either not provided to local people, or is only aimed at a few representatives, who then have the knowledge to operate and maintain the SPSs.

Implications for an inclusive, sustainable, and large-scale implementation
In terms of large-scale implementation, external experts present a fast and easily implementable solution to the need for expertise in installing the solar panels[10,30,37]. The lack of knowledge building, however, might lead to a high dependency on external actors for operation and maintenance[10,11,30,35]. Regular visits from the external expert are needed to ensure long-term functioning of SPSs, which might pose a challenge for the government as consistency needs to be ensured and most remote communities may be hardly accessible. Without proper engagement with the communities, the contact between the communities and the external experts might remain inconsistent, posing issues for maintenance of the SPSs[10]. The lack of inclusivity and knowledge building thus causes challenges for long-term sustainability of the SPSs.

4. *Employment opportunities*

Description
The economic opportunities are largely available to external experts responsible for the installing of SPSs and solar panels in the communities.

Implications for an inclusive, sustainable, and large-scale implementation
Having to employ only its own experts, the government can ensure a fast large-scale implementation. Furthermore, employing external tariff-collectors gives the government more control over the regulation and operation of the SPSs, also in terms of economic costs. However, as many remote areas may not be accessible, relying on external tariff-collectors causes inconsistencies and delays in payments. This might influence the long-term sustainability of these projects[10]. Additionally,

without economic opportunities for people from within communities, there might be a lack of motivation for the locals to actively engage with the technologies[35]. Many might still be relying on other jobs to secure a living and not have enough motivation or capacity to operate and maintain the solar panels[30]. Thus, inclusivity is being compromised.

5. *Implementation process*

Description

The initiation of the implementation comes as a top-down approach from governmental bodies. The governmental body is responsible for regulations and setting up the implementation process of the SPSs and solar panels, without the consultation or deeper collaboration with the remote communities affected.

Implications for an inclusive, sustainable, and large-scale implementation

A top-down approach allows a relatively fast and efficient large-scale implementation, however compromises on the inclusion of the communities in the implementation process. Having only a few people in the communities as representatives and responsible ones for the operation of the technology allows for efficient communication in terms of bureaucracies, however, leads to less community involvement in the process[10,37]. The latter leads to low sense of ownership towards the implemented technologies, posing challenges for long-term sustainability[10,30,35]. Additionally, remote communities might different significantly in terms of their needs. Not taking these differences into account in the implementation process, due to low engagement with communities, might fail a successful inclusive, sustainable and large-scale, implementation[35].

Implications of SPTs for access to ownership

Expertise can be easily ensured by employing available external experts, using governmental resources[11,30,35]. It might be easier to send experts who already possess the necessary knowledge than training new people for installation[40]. Organically printed panels are easily operatable, thus a lower level of knowledge is required for their operation in comparison to conventional SPSs[11].

However, this pathway poses a challenge for the long-term operation and maintenance of the implemented solar panels, as the local population lacks the necessary knowledge[10,35]. In this case, regular contact between the expert and the community representatives needs to be ensured, to serve as a ‘safety net' for the communities, once problems with the technologies occur[10,30]. This needs to be taken into consideration when looking at the long-term sustainability of SPSs.