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Off-grid Solar Products Going Circular

Exploring the potential for repair, refurbishment and remanufacturing strategies and business models for Solar Home Systems and Solar Lanterns in India

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Abstract

Off-grid solar products play an essential role in increasing and improving rural energy access, thereby reducing poverty and mitigating climate change. Experiencing fast market growth in Central and Southern Asia and Sub-Saharan Africa, off-grid solar products will represent 50% of the newly established electricity connections in the world between 2017 and 2030. Despite such benefits and market success, there is an increasing concern among academia and policy makers about the end-of-life management of solar PV. As a response to issues of natural resources depletion and waste generation, the concept of the circular economy and the role of circular business models have gained momentum amongst academia and practitioners. Nevertheless, the off-grid solar industry still mostly follows the “take, make, dispose” mantra of the linear economy. Consequently, this research seeks to explore how circular business models could be designed to extend the product life of two major categories of off-grid solar products: solar home systems (SHS) and solar lanterns (SL). This research used an explorative case study design taking India as a relevant market. It concludes that, among the three studied product extension strategies, repair and maintenance services would be prioritised in India by Original Equipment Manufacturers (OEMs) and Original Equipment Suppliers (OESs), over refurbishment and remanufacturing. Four strategies to accelerate repair and maintenance are presented, leading to the proposition of a new repair and maintenance business model. Accelerating the uptake of repair business models in the industry could benefit from the integration of repair and maintenance services and their monitoring into governmental schemes’ tendering requirements. The findings demonstrate that numerous market and policy barriers still compromise the attractiveness of refurbishment strategies. However, the research suggests large OEMs and OESs to pilot refurbishment activities for SHS in the Indian market to further understand how to operationalise refurbishment strategies into viable business models. Areas of future research include defining in greater details business model components for the proposed repair business model as well as conducting a comparative study using an action-based research methodology to enhance the process of circular business model innovation.

Keywords: circular economy, business model, circular strategy, off-grid, photovoltaics

Executive Summary

Through a large variety of products, off-grid solar solutions enable a single consumer, a household, a business, a kiosk or a school to have access to electricity for numerous purposes such as lighting, mobile charging and use of other appliances (Mandelli, Barbieri, Mereu, & Colombo, 2016). These decentralised systems increase rural energy access , thereby contributing to reducing poverty and mitigating climate change (International Energy Agency, 2018b; Lopez, 2015). Hence, off-grid solar products are a crucial contributor to achieving the United Nations Sustainable Developments Goals for energy, poverty and climate action in countries with high deficits to energy access. As one of the world's top 20 access deficit countries, India still counts 12% of its population without access to electricity. Being the world's largest market for off-grid solar products in 2018, the country plays and will play a major role in off-grid solar sales, as market projections highlight its high growth potential for the coming years (Gogla & cKinetics, 2019).

Despite such benefits and market success, there is an increasing concern among academia and policy makers about the end-of-life management of solar PV (Salim, Stewart, Sahin, & Dudley, 2019). In India, significant volumes of end-of-life or defect batteries and solar panels are expected to rise in the 2019-2024 period (Khetriwal and Kaddouh, 2018). Without an appropriate end-of-life management strategy, such waste streams are likely to be dumped or to be recycled by the informal sector, leading to negative environmental and human health impacts. In addition, solar panels, batteries and light-emitting diodes contain finite and valuable materials, including metals and rare earth materials, which need to be preserved.

To minimise waste, emissions, energy leakages and preserve resources, the concept of the circular economy has proven itself as an alternative economic paradigm (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). Circular strategies preserving the product's complexity, integrity, embedded energy and labour are expected to generate numerous environmental and economic benefits. Still, the adoption of product life extension strategies (i.e repair, refurbishment, and remanufacturing) and their operationalisation in business models remain mostly unexplored in the solar PV and off-grid industry, both in the currently published academic literature as well as in practice. However, research on repair, refurbishment and remanufacturing business models is needed as circular business models are considered a key enabler in accelerating the uptake of the circular economy (Ellen MacArthur Foundation, 2015).

Research questions and methodology

To minimise waste of off-grid solar product components and to preserve materials flows, this research seeks to explore how circular business models could be designed to extend the product life of two major off-grid solar products: solar home systems (SHS) and solar lanterns (SL) in India. To do so, it aims to answer three research questions:

RQ1: Which circular business strategies to extend product life of solar home systems and solar lanterns could potentially emerge in the context of India?

RQ2: What types of value proposition, value creation, value delivery and value capture for circular business model seem possible in such context?

RQ3: What are the drivers and barriers to the implementation of such product life extension strategies and business models?

The intended audience of this research are researchers in the field of circular business strategies and business models, and in particular researchers with interest in the sustainability aspects of

off-grid solar products. The audience also includes Original Equipment Manufacturers (OEMs) and Original Equipment Suppliers (OES) of solar home systems and solar lanterns operating on the Indian market, Indian policymakers, as well as the consultancy group Sofies under the scope of the Solar Waste Action Plan project in India. The findings of this study might also be of interest to actors along the off-grid solar products value chain in other countries where solar home systems and solar lanterns experience strong market growth.

To answer the three above research questions this thesis followed an explorative case study design. Methods of data collection include a comprehensive literature review of academic and grey literature, which enabled the construction of the conceptual framework for this research. This framework guided the data collection in 16 semi-structured interviews, and two informal interviews performed either face-to-face in Delhi, India or by phone/Skype/Zoom.

Main findings

The findings show that, among the three studied product life extension strategies, repair and maintenance services for SHS and SL could more easily emerge on the Indian market. Three identified strategies to catalyse repair and maintenance services are 1) integrating a remote monitoring system into SHS, 2) providing annual maintenance contracts, and 3) enabling lithium-ion battery replacement through the supply of spare parts and change of product design. The research suggests that the creation of an Indian coalition for repair among OEMs and OESs would enable economies of scale as well as increase customers' trust in repairs and their willingness to pay for such services. In addition to repair, OEMs/OESs also have the promising opportunity to offer refurbished SHS as donations to disadvantaged communities and to conduct a pilot for collection and refurbishment of defect SHS. Lastly, remanufacturing has not been identified as an opportunity given the small manufacturing base of off-grid solar components in India.

In such a context, the research proposes the integration of the above-described R&M strategies into one business model. The value proposition of this business model focuses on offering reliable electricity services at lower life cycle costs, with shorter downtimes and high convenience of repair and maintenance services. This value proposition would be of interest to SHS and SL customers looking for convenience of repair services and/or looking for easy battery replacement. Its delivery relies on close OEMs/OESs customer relationships, strongly developed channels of customers services, availability of trained local technicians, as well as products designed for repair including an Internet-of-Things (IoT) technology for remote controlling of SHS performance. In terms of value capture, business model revenue streams include lithium-ion replacement batteries sales, used lithium batteries sales to recyclers, annual maintenance contracts and monthly payment through the Pay-as-you-go system. This financial structure would be viable as long as revenues streams outweigh the product and service costs and enable the focal organisation to reach its required margins.

Strategies and business models' challenges for repair include the non-adaptability of the product design to repair activities, the non-availability of standardised spare parts and the difficulty to provide affordable repair services to the last mile that rural households are willing to pay for. However, growing demand for repair services and the implementation of more stringent tendering requirements for R&M service monitoring in government programs could accelerate R&M service provision. The introduction of a clear policy framework and standards, defining refurbishment activities and refurbished products, and the identification of strong market demand for second-hand SHS could accelerate refurbishment strategies in the off-grid solar sector. Numerous challenges for refurbishment remain. These include the difficulty to supply used products at the right quality, price and volumes, the technical feasibility of refurbishing

SHS and SL, as well as low customer demand and inappropriate policies and standards for refurbishment.

Key recommendations for OEMs/OESs and policymakers

Based on the above findings, key recommendations are made to accelerate the uptake of product life extension strategies in the off-grid solar product value chain in India and other markets.

For OEMs and OESs in India and in international markets – To protect the off-grid solar industry's image and build customer trust, the research strongly suggests OEMs and OESs to further integrate repair strategies for SHS and SL into their business models as well as to engage with business model experiments for refurbishment. Influencing policymakers to remove hindering factors for circular business model innovation, via industry associations such as GOGLA, would also accelerate the transition of the industry towards the circular economy.

For actors of the SWAP project – The results suggest the consultancy firm Sofies to integrate repair business models in its current roadmap for a sustainable solution for end-of-life management of off-grid solar products in India. Such a recommendation would influence partnered OEMs and OESs to consider and implement repair strategies into their BMs. Besides, it would encourage Sofies in evaluating the potential complementary of repair strategies with the development of its recycling blueprint in India.

For Indian and foreign policymakers – Accelerating repair and maintenance would require policymakers to strengthen government schemes' tendering requirements. Formalising refurbishment activities and building process standards/certifications would remove the most limiting factors for industry actors. Lastly, incentives for Indian off-grid solar products and components manufacturers would accelerate product design changes for repairability and disassembly.

Academic contribution and further research

This thesis contributed to advance the current knowledge on the end-of-life management of solar PV and more precisely of solar home systems and solar lanterns. Furthermore, this research highlighted that the decision of off-grid solar firms to adopt repair and maintenance strategies is influenced by a range of additional factors. These factors include the existence of tendering requirements for repair, the integration of repair into the overall business strategy as well as customers' product knowledge and the use of new technology into SHS. Lastly, the decision of off-grid solar firms to adopt refurbishment strategies is also influenced by the technical feasibility for refurbishment. Further research is needed to confirm the findings of this thesis using the same unit of analysis but addressing the methodological limitations of the study and integrating growing product categories such as solar pumps. Lastly, Life Cycle Analysis (LCAs) would validate the environmental relevance of prioritising repair and maintenance over refurbishment and remanufacturing.

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Abbreviations

BM	Business Model
BMI	Business Model Innovation
CBM	Circular Business Model
CBMI	Circular Business Model Innovation
CE	Circular Economy
EOL	End-of-Life
LCAs	Life-Cycle Analysis
LED	Light-Emitting Diodes
OEMs	Original Equipment Manufacturer
OESs	Original Equipment Supplier
PV	Photovoltaic
RE	Resource Efficiency
R&M	Repair and Maintenance
SBM	Sustainable Business Model
SBMI	Sustainable Business Model Innovation
SHS	Solar Home Systems
SL	Solar (Portable)Lanterns

1 Introduction

In 2018, about one billion people in the world – 13% of the global population- did not have access to electricity (International Energy Agency, 2018). 87% of the global unelectrified population live in often isolated and scattered populated rural areas, which makes public grid extensions technically and economically complex (Alliance for Rural Electrification, 2016; International Energy Agency, 2018). Therefore, decentralised energy solutions are needed to provide reliable, sustainable and modern energy for all (i.e. Sustainable Development Goal n°7) as well as to ensure that all men and women have access to basic services (i.e. Sustainable Development Goal Target 1.4) (International Energy Agency, 2018b; Lopez, 2015; United Nations, 2015). Beyond challenges of energy access and poverty reduction comes the global urgency of mitigating climate change. Indeed, the 2014 IPPC report urges to increase the current share of low-carbon energy supply from 30% to 80% by 2050 (IPPC, 2014). Among low-carbon energy solutions, off-grid solar products and mini-grid systems would be most cost-effective for 50% of the newly established electricity connections made in the world between 2017 and 2030 (International Energy Agency, 2017). Such connections are likely to take place among the top deficit access countries in Central and Southern Asia as well as Sub-Saharan Africa (International Energy Agency, 2018).

As one of the world's top 20 access deficit countries, India still counts 12% of its population without access to electricity. The Indian urban-rural chasm remains wide as 96% of the country's unelectrified households are located in rural areas (International Energy Agency, IRENA, United Nations Statistics Division, World Bank Group, & World Health Organizaton, n.d.). Therefore, off-grid solar products (i.e. solar lanterns, multi-light systems, solar home systems, solar pumps, solar freezer and solar streetlights) are effective decentralised energy solutions to achieve rural electrification in India. Those products mostly provide basic lighting, back-up lighting, mobile charging as well as appliances connection and entertainment (Gogla & cKinetics, 2019). In 2016, 4% of the Indian population relied on solar lights below 11W, and about 0.4% of the Indian population used off-grid solar products above 11W for Tier 1[1] services and beyond (International Energy Agency, 2018a). Despite India's strong political commitment for grid extensions, off-grid solar products still hold tremendous potential to be a reliable source of electricity in numerous Indian States (Gogla & cKinetics, 2019). Indeed, with income increases and higher energy demand, the private player market is likely to double or triple in value by 2023. The off-grid solar product market has also been and will continue to be supported by government programs (Gogla & cKinetics, 2019).

1.1 Problem definition

Off-grid solar product unlock numerous economic, environmental and social benefits ,as further explained in Chapter 3.4 (Gogla & Altai Consulting, 2018). Despite such benefits and a promising market growth, very little attention, both in practice and in academia, has been given to the full life cycle of sustainability aspects of solar PV systems, especially end-of-life strategies (Salim et al., 2019) and material use (Strupeit & Bocken, 2019). According to the International Renewable Energy Agency, between 1.7 to 8 million tonnes of solar panels would reach their end-of-life by 2030, which would result in a significant environmental challenge but also a strong economic opportunity (IRENA, 2019).

[1] The Multi-Tier Framework assigns every household to a Tier from 0 to 5, which indicates the level of energy services provided. Such evaluation is based on seven indicators: capacity, service hours, reliability, voltage fluctuations, affordability, legality and safety. Households in Tier 0 do not have meaningful access to energy, while households in Tier 1 enjoy basic lightning and charging services. Tier 2 refers to charging of small appliances, Tier 3 to formal grid connection but limited services, Tier 4 for energy supply supporting refrigeration. At the top of the multi-tier framework (Tier 5), households enjoy continuous access to service (International Energy Agency, 2018a).

The environmental challenge of off-grid solar products originates from the different lifespans of products components (i.e. a solar panel, a battery, controller/inverter, cables, LEDs, etc.). While a solar panel has an average lifetime of 25 years, batteries are expected to last between 3 to 7 years (Sinha-Khetriwal, Kaddouh, & Magalini, 2018). Without an appropriate waste management strategy in the country, the dumping of such post-consumption waste streams would lead to significant environmental impacts such as contamination of soils and waters from hazardous materials contained in off-grid solar components (Magalini et al., 2016). Such negative impacts are already being faced by countries in East Africa (Yee, 2019) and are likely to arise in India as the first significant waste volumes of batteries from solar home systems and solar lanterns are expected to rise by 2019-2021 and by 2024-2029 for solar panels (see Section 3.4). Despite a waste management issue for the country, off-grid solar waste also becomes a growing challenge for the solar industry as more and more investors evaluate environmental and social criteria of energy solutions (Yee, 2019).

In addition to the necessity to limit off-grid solar waste, off-grid solar products contain valuable metals and rare earth materials whose supply is limited. Solar PV can contain aluminium, copper, indium, steel, lead, nickel, silver and zinc, glass and silicon (World Bank Group, 2017). Lead-acid batteries contain lead and steel while lithium-based batteries include aluminium, cobalt, lithium, manganese, nickel and steel. Laslty, light-emitting diodes (LEDs) include lead, copper, nickel, silver and gold (European Commission, 2011). As off-grid solar products contain resource-constrained metals, material recovery strategies are highly needed in the solar PV industry (IRENA, 2019). Indeed, India is not immune from resource dependency issues, especially on silver and copper for solar PV production (Arora et al., 2018).

To minimise waste, emissions, energy leakages and preserve resources, the concept of circular economy has proven itself as an alternative economic paradigm (Geissdoerfer, Savaget, Bocken, et al., 2017). Circular economy strategies aim to slow resource loops (i.e. extend utilisation of products) or to close resource loops (i.e. re-circulating flows of resources by closing the loop between post-use and production) (Bocken, De Pauw, Bakker, & van der Grinten, 2016). Product life extension strategies such as repair, refurbishment and remanufacturing should be favoured over recycling as they use materials at their highest value and preserve the product's complexity and embedded energy and labour (Ellen MacArthur Foundation, 2015). These strategies, also called, value retention processes, are expected to generate higher social, economic, environmental value among numerous sectors (Nasr & Russell, 2018), including the off-grid solar industry (IRENA, 2019). Despite such benefits, the literature on end-of-life management of solar PV has mostly focused on the scale of the waste issue (Weckend, Wade, & Heath, 2016), on new and current recycling technologies (Salim et al., 201; Xu, Li, Quanyin, Anesia, & Congren, 2018) as well as on end-of-life management policies (Malandrino, Sica, Testa, & Supino, 2017; Weckend et al., 2016). Only very recent and limited literature started to explore inner-loop strategies in the solar PV industry (Arora et al., 2018; Franco, Grösser, Tsanakas, Lemaire, & Wang, 2018; Sica, Malandrino, Supino, Testa, & Lucchetti, 2018; Strupeit & Bocken, 2019; Tsanakas et al., 2019) and in the off-grid solar industry (Cross & Murray, 2018; Gogla, 2019a; Salim et al., 2019). Hence, despite their value retention potential, inner-loop strategies of repair, refurbishment and remanufacturing in the off-grid solar industry remain unsufficiently explored.

For organisations to operate circular strategies, the concept of circular business models has emerged, supporting businesses delivering economic, environmental and social value (Nußholz, 2017). Despite their noticeable progression over the last decade and their high potential to be drivers of the circular economy (Bocken et al., 2016; Lewandowski, 2016), circular business models are not yet widespread in business operations (Ritala, Huotari, Bocken, Albareda, & Puumalainen, 2018). The off-grid solar industry is no exception to this statement as the sector has only seen the emergence of a very few circular business models such as Solar Worx and Azuri, mostly operating across Sub-Saharan Africa (Gogla, 2019a). However, the role of business models is crucial to accelerate the uptake of the circular economy, along with circular design, enabling factors and reverse logistics (Ellen MacArthur Foundation, 2015). Hence, further research is needed to operationalise inner-loop strategies in new or existing business models of the off-grid solar industry.

1.2 Objective and research questions

To address the above-described problems, this research aims to catalyse circularity in the off-grid solar sector in India. To contribute to this aim, the objective of this research is to explore how circular business models could be designed to extend the product life of two major off-grid solar products: solar home systems (SHS) and solar lanterns (SL) in India.

To address the above objective, this paper seeks to answer the following three research questions:

RQ1: Which circular business strategies to extend product life of solar home systems and solar lanterns could potentially emerge in the context of India?

RQ2: What types of value proposition, value creation, value delivery and value capture for circular business model seem possible in such context?

RQ3: What are the drivers and barriers to the implementation of such product life extension strategies and business models?

1.3 Scope and limitations

The scope of this study has been limited geographically to India and in terms of technology and market segments to two off-grid solar products: Solar Home Systems (SHS) and Solar Lanterns (SL). Among all product life extension strategies, this research only tackles repair, refurbishment and remanufacturing strategies and business models.

The choice of solar home systems and solar lanterns is justified by the products' large sales volumes on the Indian market. Indeed, India is the single largest market for solar lanterns and, solar home systems are expected to be the fastest-growing consumer solar product segments in the next five years on the private market (Gogla & cKinetics, 2019). The choice of product categories was also limited to two, due to practical limitations of accessing and interviewing a wide variety of stakeholders in the Indian context. Studying and comparing solar home systems and solar lanterns enriched the research findings as product composition and design highly differ between SHS and SL. Lastly, strategies of reuse and repurposing were not included in this research as they are less widely explored in the literature and usually conducted by the informal sector in India.

It is important to note here that this research only considers solar home systems defined as decentralised systems which "supply electricity to a nearby single consumer, household, a kiosk, a rural industry, school etc" (Mandelli, Barbieri, Mereu, & Colombo, 2016, p1626) and not micro-grids. Indeed, the research's scope does not include micro-grids, defined as "systems which supply power to several, similar or different, consumers" (Mandelli, Barbieri, Mereu, & Colombo, 2016, p1626) and which required a distribution grid.

In terms of limitations, the study of two specific off-grid products leads to generalisability issues for the whole category of off-grid solar products. In addition, the collected stakeholders' perspectives on potential business models are unlikely to represent the diversity and complexity of market dynamics in India, leading to generalisability of the findings to the whole country. Besides, the choice of India also lead to practical limitations as the author has limited knowledge of the Indian context, its language, cultural and regional differences.

1.4 Review of methodology

To answer the three above research questions, this thesis followed an explorative case study design. Case studies have been widely used to investigate "a contemporary phenomenon in depth and within its real-life context" (Yin,2009, p18) and to analyse circular business models and circular business model innovation (Bocken, Miller, Weissbrod, Holgado, & Evans, 2017; Geissdoerfer, Morioka, Carvalho, & Evans, 2018; Linder & Williander, 2017). Methods of data collection included a comprehensive literature review of academic and grey literature which enabled the construction of a conceptual framework. This conceptual framework guided data collection of the 16 semi-structured interviews and two informal interviews performed either face to face in Delhi, India or by phone/Skype/Zoom. To analyse the data, the use of the grounded theory framework and coding tool NVivo enabled the author to identify common themes and concepts amongst the interviewees' findings.

1.5 Ethical considerations

This project has been conducted with the support of the consultancy group Sofies and the Producer Responsibility Organisation Karo Sambhav, operating in India. Sofies provided numerous written documents as well as contacts which are part of the undergoing Solar Waste Action Plan[2] as well as financial support allowing the author to move to Delhi, India to conduct her research temporarily. In addition, Pranshu Singhal, CEO of the organisation Karo Sambhav put the author in contact with relevant potential stakeholders for data collection and enabled the author to work from Karo Sambhav's offices located in Delhi. The topic of this research and its design was discussed and commonly agreed upon with Sofies and Karo Sambhav. However, the conduct of this research and its findings were not influenced by either of these organisations.

Ethical considerations for this research mostly concerned the interviews process and data. All interviewees participation in this research was voluntary. Prior to the interview, participants were informed of the goal of this research through an explanatory email and a presentation specifying the collaboration of the author with Sofies and Karo Sambhav. Before the interviewee process started, interviewees were asked if the interview could be recorded electronically and if they agreed to disclose their name and their position within the organisation. In cases where interviewees required to remain anonymous, the individual's and the organisation's names were replaced in the thesis by a generic position in company n°X. Lastly, interviewees were individually contacted and asked to verify the information and provided quotes within the thesis draft prior to its publication. In addition, the outcomes of this research were not considered as potentially harmful for the reputation, dignity or privacy of the interviewees. The data collected in records and notes taking are stored electronically in the author's files and cloud.

1.6 Audience

This research aims to interest researchers in the field of circular business models in a developing country context and researchers with a focus on off-grid solar products. Given that this research

[2] The Solar Waste Action Plan is a project performed by the consultancy group Sofies in India, for Signify Foundation and members of the industry association GOGLA. It aims to "design and test a blueprint for responsible management of solar waste in India and upscale local capacity" (Sofies, n.d.)

focuses on one of the SWAP dimensions, this case study also targets Sofies' teams and their final clients Signify Foundation and GOGLA Members, an industry association of off-grid solar actors. The targeted audience also encompasses organisations which are likely to identify a business opportunity in establishing or being part of a SHS and/or SL repair, refurbishment and/or remanufacturing business models. Lastly, the findings of this research target Indian and international policymakers seeking to remove hindering factors and implement enabling conditions for such business strategies and models to emerge and sustain in the long run.

1.7 Disposition

Following the presentation of the academic and practical issues originating from the "take, make, dispose" mantra currently dominating in the off-grid solar sector in India, *Chapter 1* offers an overview of the research focus, its objectives and targeted audience.

Chapter 2 details the rationale and methodology used for conducting an explorative case study using qualitative data collection and analysis methods. It describes the processes used by the author to collect and analyse both academic/grey literature and semi-structured interviews.

Chapter 3 presents the two off-grid solar products of focus of the study: solar home systems (SHS) and solar lanterns (SL). Their role, benefits as well as their components and materials composition are described. An overview of the current and future market dynamics in India is offered to understand the importance of such products in India's electrification process.

Chapter 4 develops a comprehensive review of key concepts and theories on product life extensions strategies and business models as well as the state of circularity strategies in the off-grid solar sector, building the conceptual framework used for data collection and analysis. Following the conceptual framework, *Chapter 5* presents the findings of the research which answers the three stated research questions.

Lastly, *Chapter 6* presents the main conclusions on how to further explore repair and refurbishment business models in the off-grid solar sector in India with both business strategies and policy recommendations. This chapter highlights the research contribution in the field of circular business models of off-grid solar products and outlines several axes of future research for their operationalisation.

2 Methodology

This chapter presents the methodology used to answer the previously established research questions. Section 2.1 justifies the choice for an explorative case study design, while Section 2.2 explains in greater details the methods employed for data collection and data analysis. The limitations of such methodological choices are presented in Section 2.3.

2.1 An explorative case study design

Social research can use numerous research designs including experimental design, cross-sectional design, longitudinal design, case study design and comparative design (Bryman, 2012). The research design of this study is based on case study methodology. According to Yin (2009, p18), a case study is "an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between the phenomenon and the context are not clearly evident". In this study, the rationale for choosing a case study research design lied in the investigation of the contemporary phenomenon of circular business model innovation in the real-life context of the SHS and SL markets in India. Case studies have been widely used in literature to analyse circular business models and circular business model innovation. Examples of such methodology choices include Linder & Williander (2017), Geissdoerfer, Morioka, Carvalho, & Evans (2018), Vermunt, Negro, Verweij, Kuppens, & Kekkert (2019) and Bocken, Miller, Weissbrod, Holgado, & Evans (2017) among many others. Therefore, it was deemed reasonable to use a case study as the research design of this thesis.

Case studies are classified as exploratory, explanatory or descriptive (Streb, 2010a, 2010b, 2010c). Exploratory research is most appropriate when exploring a relatively new field of study, and when the data necessary to formulate hypothesis are not yet available (Streb, 2010c). This research was well suited for an explorative case study with a forward-looking approach. Indeed, no hypotheses could yet be tested for this research, and no clear explanations of the phenomena could be identified in the context of circular strategies of off-grid solar products in India. In addition, the author has followed a combination of inductive and deductive approach. A deductive approach was used by the author when analysing what is currently known in the field of extending product life strategies, circular business model and business model innovation. It also included testing empirically these findings and observations through several data collections methods with the objective nourish the current state of theory. During the empirical research, the author used an inductive approach when discovering novel factors influencing business model strategy and strategy operationalisation. Hence, the author conducted this inductive and deductive approach iteratively and remained open to new elements of analysis during the research process (Streb, 2010c).

Case studies offer numerous benefits but also present essential limitations. On the one hand, a case study research design enables to get an in-depth understanding of a specific phenomenon (Creswell, 2014; Yin, 2009) as well as a holistic and real-world perspective on this phenomenon (Yin, 2014). Benefits of such a case study approach include a high level of flexibility for data collection as well as the ability to define further questions and hypotheses for following studies (Streb, 2010c). Limitations include aspects of social research evaluation such as reliability, replication and validity (Bryman, 2012). In the context of a case study research design, Bryman (2012) points out that there is no consensus in the literature on whether all of these factors are significant or not. Despite this, the external validity aspect is of particular concern for a case study, as the analysis of one case cannot represent other cases (Bryman, 2012; Yin, 2009). The following strategies have been followed to ensure that this research meets the social research criteria established by Bryman (2012) and (Yin, 2014):

Reliability & Replication[3] *Definitions: "Reliability is concerned with the question of whether the results of a study are repeatable" (Bryman, 2012, p46) and "to be sure that, if a later investigator followed exactly the same procedures as described by an earlier investigator and conducted the same case study all over again, the later investigator should arrive at the same findings and conclusion" (Yin, 2014,p36) -* Strategies to ensure reliability and replication included 1) to detail all methodologies for research design, data collection and analysis; 2) to archive all research materials in a case study database available upon request; and 3) to make available questionnaires in Appendix to allow future investigators to replicate the research.

Measurement Validity (also called construct validity) *Definition: "the question of whether a measure that is devised of a concept really does reflect the concept that it is supposed to be denoting" (Bryman, 2012, p47).* Measurement validity was enhanced by using multiple sources of evidence (literature review and interviews) as well as by relying on existing concepts and theories on circular business strategies, business models and business model innovation.

Internal Validity *Definition: "Interval validity is concerned with the question of whether a conclusion that incorporates a causal relationship between two or more variables holds water" (Bryman, 2012, p47).* Strategies to increase internal validity included 1) a systematic literature review and use of business model theory; 2) the use of data triangulation through multi-stakeholders interviews and the use of both academic and grey literature; and 3) the interviewees' reviews of the information and quotes included in the thesis.

External Validity *Definition: "External validity is concerned with the question of whether the results of a study can be generalised beyond the specific research context" (Bryman, 2012, p47).* The generalisability of this research might be compromised given the diversity of actors in the off-grid solar space in India. To cope with such issue, this research aimed to represent a multi-stakeholder approach to depict the views, opinions and perceptions of numerous actors from large businesses, SMEs, foundations and research institutes. However, this study still holds external validity for countries which experience similar market dynamics including 1) a strong SHS and SL market growth; 2) an important public market driven by public procurement; 3) the non-existence of circular policies impacting the off-grid solar industry.

2.2 Data collection and analysis

This section presents the rationale for a qualitative approach as well as the methodologies for data collection and data analysis.

2.2.1 Rationale for using a qualitative approach

While qualitative methods are not always the unique and only choice for a case study research design (Bryman, 2012), this thesis only relied on a qualitative research strategy. Qualitative research was best suited as repair, refurbishment, and remanufacturing of off-grid solar products remains insufficiently understood (Walliman, 2006), as argued in Chapter 4. Qualitative methods also enable the researcher to get the point of view of the research participants through context-dependent, micro and rich data (Bryman, 2012). To answer the research questions previously established in Chapter 1, the author needed to understand the participants' meanings and the participants' natural setting (Creswell, 2014). Both of these elements supported the choice of qualitative methods (Creswell, 2014). Through the whole research process, the author remained open to any data collection opportunity (e.g. conferences, conversations) allowing for a flexible and cyclical design (Creswell, 2014; Eden & Huxham, 1999). In addition, qualitative methods are well suited in this context as they enable to generate new concepts and theories rather than

[3] For Yin (2014), replication and reliability are extremely closely related. This thesis will therefore study them together.

to test theories. Therefore, this research has used several qualitative sources of data which include both secondary data through a literature review of academic and grey papers and primary data through interviews(Creswell, 2014; Yin, 2009). Such qualitative sources of data are presented below.

2.2.2 Literature review

The literature review was built using both academic and grey literature and followed a narrative form (Bryman, 2012). The reviewed academic literature included peer-reviewed journal articles, conferences papers and books published in English and accessible by the end of July 2019 on Lund University library tools (i.e. LubSearch), Scopus.com or Research Gate. The stated research objective and research questions directly influenced the choice of search keywords presented in Annex A. The author also followed a snowball approach which consists of reviewing additional references identified in papers' list of references (Wohlin, 2014). The objective of this review was to determine the implications of product life extension strategies on BMs, along with the process of business model innovation.

The topics reviewed by the academic literature provided:

(1) an understanding of what extending product life strategies are, how are they implemented and what challenges arise from them;
(2) the key dimensions of circular business models and how they diverge from classic business models; and
(3) the process of business model innovation (BMI), circular business model innovation (CBMI) and the role of experiments.

As limited information in academic literature was found on SHS and SL in the Indian context, the author then relied on additional grey literature with the objective to understand and present her case. Grey literature mostly relied on the internal study entitled "Feasibility Study" written by the consultancy firm Sofies in 2018 and the 2019 GOGLA market report on the Indian off-grid solar product market. Besides, the author researched specific reports on the CE in India, off-grid market reports and specific examples of circular economy strategies in the off-grid sector on Google.com. The objective of this grey literature review was to get a deeper understanding of SHS and SL market dynamics on the Indian market as well as products' use, components and waste volumes associated.

The topics reviewed by the grey literature provided:

(1) the current state of SHS and SL on the Indian market;
(2) products composition;
(3) expected waste volumes of SHS and SL in the Indian market; and
(4) the product life extension strategies and business models implemented in the industry.

To analyse the data, all sources of data were systematically computed into three synthesis matrices on 1) circular economy and product life extension strategies, 2) BMs and CBMs and 3) BMI and CBMI. In each of these synthesis matrices, the author manually entered selected data into an excel spreadsheet. Reducing the data and displaying it on a systematic excel spreadsheet enabled the author to identify common themes and concepts within all sources of relevant literature. These themes and concepts were built in a first draft of the conceptual framework in Chapter 4, which then was used to guide data collection. In addition, the author assessed the gathered literature and aimed to present as much as possible a critique of the presented literature and the underlying assumptions on which presented arguments were based (Walliman, 2006).

As additional literature was identified throughout the process, this synthesis matrix was adjusted and completed along the way as an iterative process.

2.2.3 Semi-structured and informal interviews

For this research, qualitative data collection methods mostly relied on interviews due to their flexibility (Walliman, 2006). The author's interest in gathering independent thoughts, opinions and views of a variety of stakeholders mostly expressed through open-ended questions justified the use of semi-structured questionnaires (Adams, 2015). The author's objective was to 1) get stakeholders' perceptions on the current challenges and drivers for CBMI in the off-grid solar sector and 2) gather ideas on how new business strategies could potentially advance repair, refurbishment or remanufacturing BMs. Given the choice of research questions and the case study design, interviewees were identified as key informants for data collection.

Interviewees were selected based on their involvement with the Solar Waste Action Plan (SWAP) conducted by Sofies and existent partners or contacts known by the representative Pranshu Singhal of Karo Sambhav. Both Sofies and Karo Sambhav acted as first contact points with potential interviewees, given their extensive networks of contacts in the off-grid solar industry and the Electrical and Electronic Equipment (EEE) recycling sector in India. Therefore, identified relevant stakeholders' representatives were first contacted by phone or email by representatives of these two organisations and then directly contacted by the author. Some interviewees further put the authors in contact with additional experts enabling a snowballing effect. The author conducted sixteen semi-structured interviews in English between July 4th and August 8th, 2019 either face-to-face in New Delhi, India or through Skype/phone or Zoom calls. A list detailing the name of interviewees, their position as well as the interview date and time is available in Appendix B. Figure 1 presents in bold the ecosystem's stakeholders interviewed in this study and how many interviewees originate from that stakeholder group. The variety of stakeholders interviewed allowed the author to triangulate the collected data and evidence.

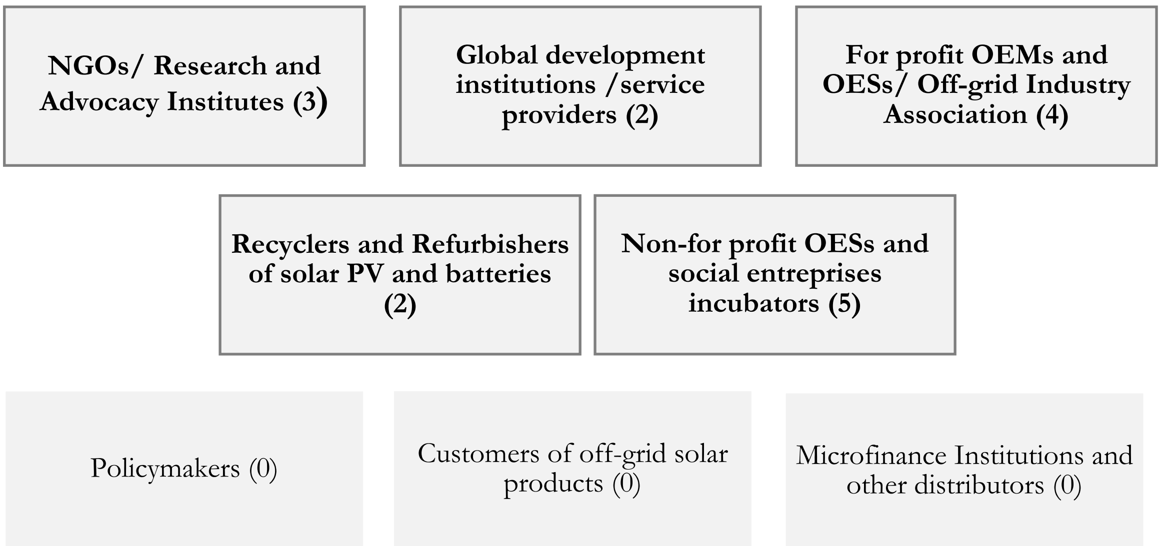

Figure 1: Off-grid solar products ecosystem's stakeholders interviewed.

Source: Own illustration.

The interview process followed a semi-structured questionnaire. Given the differences of core activities between the numerous stakeholders interviewed, one interview guideline was developed for each category of stakeholders. When organisations' activities significantly differ, a specific interview guideline was developed. An example of one interview guideline is available in Appendix C. During the interviews, and following the inductive research approach, the researcher allowed for new topics or themes to emerge. Consequently, the interview guideline was not strictly followed but only constituted a red line for the interviewer to grasp participants' perspectives on all dimensions of the conceptual framework. The semi-structured interviews were electronically recorded through a personal computer or a phone upon agreement with the interviewees. In the authors' perspective, such records facilitated the electronic note-taking process during the interview time and enabled further adjustments to the notes after the interviews. However, phone calls with experts could not be recorded due to technical issues on the authors' computer (further details available in Appendix B).

In addition, informal interviews with representatives of Solar Worx and Solar What?! (i.e. two circular companies in the off-grid solar market in Africa) were conducted. They enabled the author to better understand the companies' business model for repair, refurbishment and/or remanufacturing of SHS or SL. In this case, both companies were contacted by email by the author through the contact details available on the companies' websites and then reached through Skype for a short conversation.

To analyse the data, the author followed the grounded theory framework, which is one of the most used frameworks for qualitative data analysis (Bryman, 2012). The author semi-transcribed each conversation after each interview. Then the author completed her first round of notes taking by listening to the audio recording (when possible) and putting down additional comments and notes. Following this, the semi-transcripts were computed into the NVivo tool. Performing qualitative analysis in grounded theory widely relies on the process of coding. Coding is described as a process "whereby data are broken down into component parts, which are given names" (Bryman, 2012, p568). In this study, the author followed a two-stage approach for coding:

(1) The initial coding defined by Charmaz (2006) and explained by Bryman (2012, p569). This initial coding phase enables the author to code all transcripts fully. The objective of this initial coding is to generate as many ideas as possible to cover the data.

(2) The focused coding defined by Charmaz (2006) and explained by Bryman (2012, p569). This phase enabled the author to decide which codes made the most analytic sense and to build the final coding structure with nodes and sub-nodes in NVivo. Such a final coding structure is available in Appendix C.

Interviewees were sent a draft of the thesis on September 7th, 2019 to get respondent validation on presented quotes. This process allowed each interviewee to confirm that the authors' understanding is congruent with his/her views. Interviewees were given a week time to get back to the author with necessary corrections.

3 The market of Solar Home Systems and Solar Lanterns in India

This chapter provides an overview of the two products of focus of this research: SHS and SL. Section 3.1 offers a description of SHS and SL, their roles and their components and material composition. Section 3.2 reviews the current and projected market dynamics of SHS and SL. Section 3.3 synthetises the benefits of SHS and SL and finally, Section 3.4 overviews the state of Indian policy on SHS and SL and projects waste volumes of SHS and SL.

3.1 Key features of SHS and SL

The below-presented data originate from the feasibility study conducted by the consulting group Sofies in July 2018 for Signify Foundation entitled "Feasibility study for a pilot in Off-grid sector in India" as well as the 2019 GOGLA market analysis of off-grid solar products in India. Through the literature review, these two documents were identified as the most relevant and context-specific information to present SHS and SL in an Indian context. It is important to note here that LEDs were not the main focus of the feasibility study, which explains some missing data for such products in the below section. Table 1 describes the energy services provided by SHS and SL, their components, their battery types, their average price and power consumption. Additional information on the material composition of each component is available in Appendix E.

Table 1: SHS and SL product description and components

	Solar Home Systems (SHS)	Solar Lanterns (SL)
Energy service provided	• Basic and back-up lighting • Mobile charging • Entertainment (if TV) • Cooling (if fan/refrigerator)	• Basic lighting • Back-up lighting • Mobile charging • Entertainment (if radio built-in)
Components	• Solar panels (3-10kg) • Battery (10-25 kg) • Charge controller and/or inverter (150-900g) • Cables (1-2.5 kg) • LED (100-150 gr)	• Solar panel (400 g) • Battery (100 g) • LED (30gr) • Plastic casing (200g) • Steel (160g)
Battery Types	• Lithium-iron-phosphate • Lithium-manganese-oxide • Lead-acid	• Lithium-iron-phosphate • Lithium-manganese-oxide
Price (USD)	• From 150 USD and over depending on connecting devices	• 5-30 USD
Power consumption	• 11-100-Watt Peak (non-governmental scheme) • 100-300-Watt Peak (government schemes)	• Less than 11-Watt Peak

Source: Adapted from Gogla & Ckinetics (2019) and Sinha Khetriwal and Kaddouh (2018)

Based on the key characteristics presented in Table 1, it is worth noting the differences that exist between Solar Home Systems and Solar Lanterns. The main difference is the level of power generation of the system. A SHS provides more power which can be used for entertainment and cooling through new appliances usages. Therefore, SHS are made of a larger weight of solar panels and batteries and are 5 to 30 times more expensive than SL (depending on the appliances connected to the system). A SHS is usually modular in the sense that the components of the solar panels, lights and batteries can be plugged-in from several different brands, while a solar lantern can only be one unit that includes all components in a sealed plastic casing.

Features of these two products categories have been regulated by the Lighting Global Program, which sets international quality standards as a baseline for quality, durability and truth in advertising. While these standards do not specifically integrate dimensions of repair, refurbishment or remanufacturing, standards for battery and warranty are worth highlighting in relation to the research questions. For solar-pico products up to 10 W, the standard requires, among many points, a 1-year warranty covering the battery as well as damages linked to an ordinary product use and manufacturing defects. In addition, the battery should be protected by a charge controller and should follow the specified certifications for battery safety. The warranty must be facing consumers in the appropriate regional language and should explain to the user how to access his/her warranty . For DC solar home systems between 11 to 350 W, the warranty is of 2 years for the PV module, control box, cables, lights and system battery except for batteries included into lighting appliances associated with the product. Consumer information must either specify 1) the components that would require replacement and the instruction for replacement; or 2) the information on where components can be found and the location of service centres; or 3) a statement explaining that which components are not replaceable. Information on the replaceability of the battery should directly be visible on the consumer-facing packaging, while other information can be part of the user manual. In addition, batteries in SHS should also follow the specified certifications (Lighting Global, 2018). Only a certain percentage of SHS and SL on the Indian market apply the Lighting Global Program standards.

3.2 Overview of SHS and SL market development

With a current households market penetration of 19%, off-grid solar products still show promising market potential in India (Gogla & cKinetics, 2019; Sinha-Khetriwal et al., 2018). In the first half of 2018, India represented 30% of the global volume share of sales of off-grid solar products, a segment that includes solar lanterns, multi-lights systems[4], SHS, solar pumps, DC fans, DC TVs, DC refrigerators and solar-powered deep freezers (Gogla & cKinetics, 2019). More than 1.2 million units of off-grid solar products were sold in 2018 with a value of 58 USD million (Francioso et al., 2018). Despite the perceived saturation of the market of basic lanterns, lanterns with a 1.5 to 2.9 Watt peak, multi-light systems and solar home systems are expected to grow in the coming years (Gogla & cKinetics, 2019). In 2018, solar lanterns and multi-light systems largely dominated the Indian market, representing 82% of the market in value while SHS represented 18%. However, in 2023, the SHS segment is expected to grow in value from 18% of the market to 42% and the basic lantern will reduce from 51% to only 6% (Gogla & cKinetics, 2019). Lanterns between 1.5 to 2.9 Wp will reach 44% in 2023 and multi-light systems will reach 8% of the market. The Indian market growth is driven by consumers needs for electrification in areas which will remain unreached by the grid. In addition, growth-driving-factors include consumers' needs to have access to power back-up in case of power outages, increasing mobile-charging needs and consumption of additional appliances such as fans, TVs, and refrigerators. Off-grid solar products operate in two distinct markets: the private player market where business models are developed for B2C customers; and the government market where off-grid solar products are sold to the government for specific subsidies schemes (Gogla

[4] Multi-light systems are systems enabling basic and back-up lighting as well as mobile charging. They are usually considered as an entry-level SHS (Gogla & cKinetics, 2019).

& cKinetics, 2019). SHS and SL market dynamics on these two markets are both presented below.

The private-player market

SHS entered the Indian private player market in the 1990s but are still considered in their introductory product growth stage. Market trends indicate that the SHS segment with wattages from 100 to 400 Wp are likely to grow, especially in certain states with remaining power outages such as Jammu and Kashmir, Chhattisgarh, Jharkhand, Arunachal Pradesh, Uttar Pradesh, Bihar and Mizoram. This SHS growth is likely to be driven by the increased compatibility between SHS and other DC appliances such as fans, TVs and refrigerators. The retail price of SHS highly depends on the connected appliances that come with it. For a SHS that includes a DC TV and a DC fan will range from INR 45,000 to INR 67,000 (567 to 840 USD). Such pricing is usually beyond what Indian rural households can afford. Therefore, access to financing is considered a crucial element for this product segment. The 2019 GOGLA report on the state of the Indian market highlights the role of the unorganised sector, which is likely to assemble several components from different brands to build SHS.

Regarding solar lanterns, the category can be divided into sub-segments based on their power capacity: the basic lanterns of less than 1.49 Wp, the lanterns of 1.5-2.9 Wp (which include a charger or radio), and the multi-light systems from 3 Wp to 10.99 Wp. The basic lantern segment, mostly driven by the private player market, is currently considered mature with 7.32 million of annual estimated units being sold (Gogla & cKinetics, 2019). While the Lighting Global Product quality standards require a one-year warranty for solar lanterns (Gogla, 2019a), basic branded lanterns products usually have a two-year warranty and can run 10-12 hours per day. However, do data on their estimated lifetime was identified. Demand mostly originates from households in the states of Bihar, Rajasthan, Uttar Pradesh, Odisha, Northern-East States and regions experiencing cyclones or floods. Their price usually ranges from INR 300 to INR 700 (4-10 USD). However, basic lantern consumers start to buy larger lanterns which can satisfy their charging or entertainment needs. The growth of mobile phone subscriptions in rural areas will consequently increase the need for lanterns with a rated capacity of 1.5 to 2.9 Wp. Lastly, the multi-lighting subsegment is likely to grow due to the unreliable grid power at peak hours and due to the needs of households to upgrade their current solar lanterns. However, the multi-lighting segment is perceived as a transitional product between solar lanterns and SHS (Gogla & cKinetics, 2019).

The government-driven market

In addition to the above-presented market trends for SL and SHS, the success of such products on the Indian market can partially be explained by the increased focus given to off-grid solar power in the government energy policy. As an example, off-grid PV targets were already established under the Jawaharlal Nehru National Solar Mission (JNNSM) announced in 2010 (Ahn & Graczyk, 2012). More recently with the introduction of Saubhagya scheme in October 2017, off-grid solar power has been identified as playing an important role to reach the target of 100% household electrification by the end of 2019 (Gogla & cKinetics, 2019). Indeed, about 2.5 billion USD have been allocated in the last years to offer free ownership of 200-300 Wp SHS to 350,000 households across seventeen states under the Saubhagya scheme[5]. Such scheme results both in opportunities to provide additional product solutions to the market but is also

[5] The reader should note that the allocation of 2.5 billion USD for 352,502 households described in the GOGLA report conflicts with the average price of SHS described in Table 1. Around 350,000 units being distributed for a total investment of 2.5 billion USD would lead to an average SHS price per household of more than 7,000 USD.

likely to impact the replacement market if services of maintenance and after-sales are poorly performed. Overall, GOGLA's market analysis underlines the forecasted decline in government spent for SHS after 2021 (Gogla & cKinetics, 2019). The Ministry of New and Renewable Energy also implemented several schemes to promote SL. Examples include the one million solar study lamps scheme in 2014 in Rajasthan, Madhya Pradesh, Maharashtra, the 7 million solar study lamps under the Solar Urja Lamps schemes (for students in the States of Assam, Bihar, Odisha, Uttar Pradesh and Jharkhand) as well as the distribution of 500,000 solar study lamps in several states in 2016 (Gogla & cKinetics, 2019; Sinha-Khetriwal et al., 2018). Despite SHS and SL, many other schemes have been developed and implemented by the Indian government for additional off-grid products, such as solar pumps (i.e. KUSUM scheme) and most solar products under the Goods and Services Tax scheme. Indeed, the Indian government's priorities have recently shifted to a solar pumping subsidy scheme, as this has been identified as a potential source of additional income for rural households.

Table 2 resumes the current and estimated market sales for both private players driven and government driven SHS and SL.

Table 2: 2019 and 2023 sales units estimates for SHS and SL

	Private player driven SHS	Government driven SHS	Basic SL	SL	SL with multi-lights
2018 Average sales units	51,833	29,000	7.32 M	2.63 M	53,000
2023 average sales units	• 100 Wp (with DC fans): 100,803 – 112,901 • 200-300 Wp (with DC fans and TVs): 226-154,563 • 400 Wp (with DC fans, TVs and refrigerators): 26,708- 53,416	70,000	2.03-2.74 M	3.01-3.88 M	200,452-312,692

Source: Adapted from Gogla & Ckinetics (2019)

Manufacturing base outside and in India

The feasibility study conducted by Sofies indicates that, despite the large import volumes of off-grid products from China, there is a growing base of Indian manufacturers for off-grid solar components. In addition to lead-acid batteries that are already commonly produced in India, there is a growing ambition to develop a PV manufacturing base which could compete with Chinese PV manufacturers. Lithium-ion batteries manufacturing is also seen as an opportunity, especially as the electric car market grows. These findings are supported by the Gogla & cKinetics report (2019), which identified India as a future hub for design and manufacturing of off-grid solar products. Table 3 below resumes the major key players in the off-grid solar market.

Table 3: Main product manufacturers and main Indian off-grid solar product components present in India

Main Off-grid solar OEM	Product range	Main Solar Component OEM	Components
Anu Solar	SL, SHS, Street Light	Tata Power Solar	PV panels
Chemtrols	SL, SHS, Street Light	Waaree Energy	PV panels
D.light	SL, SHS	Vikram Solar	PV panels
DK Solar	SL, Street Light	Adani Solar	PV panels
Icomm Tele Ltd	SL, SHS, Street Light	Exide Industries	Lead-acid batteries

Indosolar Ltd	Solar Rooftop, Street Light	Amara Raja Batteries Ltd	Lead-acid batteries
Kotak Urja Pvt Ltd	SHS, Steet Light	Semyung	Lithium-based batteries
Moser Baer Solar Ltd	SL, SHS		
ONergy Solar	SL, SHS, Steet Light		
Philips Lighting	SL, SHS, Steet Light		
SELCO Solar Light Pvt. Ltd	SL, SHS, Sreet Light		

Source: Adapted from Sinha Khetriwal and Kaddouh (2018)

Key distributors operating on the Indian market

SHS consumers can directly own their off-grid solar product, fully lease it or only lease it for some time before acquiring its full ownership. Consumers can directly purchase their off-grid solar products through classic distributors including speciality shops and small individual dealers. If not purchased, SHS can be distributed by microfinance institutions, NGOs or rural agencies, government programs or companies under their Corporate Social Responsibility (CSR) programs[6]. Basic lanterns and multi-lights are distributed through local retailers, microfinance institutions and sometimes NGOs. However, microfinance institutions play a significant role in distributing 1.5 to 2.9 Wp lanterns as they finance 60% of them.

3.3 The benefits of off-grid solar products

The growing and renewed interest for small scale energy generation comes from several environmental, economic, technical, political and social factors (Mandelli et al., 2016). Such interest can be explained by the growing concern about GHG emissions, the risks associated with large plant scale investment, the increased performance of small power technologies and the need to decrease dependence from fossil fuels, among other factors. In addition, factors specific to a developing country context include the lack of accessibility of remote areas leading to high costs for grid extension (Mandelli et al., 2016; Nathan, 2014). More precisely for Nathan (2014), the unavailability of the electricity supply originates from difficulties in distributing the electricity without too much loss across remote areas, in limiting power theft, and in collecting electricity bills. Indeed, as of early 2019, GOGLA reports frequent fluctuations for household electricity supply and low electricity supply to rural areas during evening hours, which might lead households to invest in more reliable power supply (Gogla & cKinetics, 2019). In addition, the growing role played by off-grid solar products among decentralised energy solutions is due to the declining cost of its components, especially LEDs lights and lithium-based batteries (IRENA, 2019).

SHS and SL bring numerous economic, social and environmental benefits and have the opportunity to advance several SDGs (IRENA, 2019). One of the most immediate benefits is that SHS and SL enable to increase the number of daily hours of light available to households (Gogla & Altai Consulting, 2018). As an example, energy access is described as the first user-perceived benefit for both solar lantern and solar home systems in the context of Uganda (Hirmer & Guthrie, 2017). However, the implementation of an SHS will lead to different effects depending on the replacing source of light. For example, for individuals using a solar lantern and upgrading to a SHS, the improvement of light access would only be incremental (Gogla & Altai Consulting, 2018). In addition, off-grid solar products enable households to save on costs. In the case where SHS are replacing kerosene lamps and rechargeable batteries, Komatsu, Kaneko and Ghosh (2011) estimated that rural households in Bangladesh would save an

[6] Under the New Companies Act of 2013, which came into effect in April 2014, the Indian government mandates businesses with a net worth of INR 500 crore or a turnover of INR 1000 or more or a net profit of INR 5 crore to invest 2% of the company's net average profits for Corporate Social Responsibility issues (KMPG, 2018).

approximate 200-300 taka per month per household, irrespectively of the SHS wattage. Such cost savings represent between 20-30% of the households' monthly payment for SHS. Savings originate from the decrease of kerosene expenditures, the decrease of transportation for kerosene as well as the decrease in charging batteries expenditures and transportation costs for battery recharging (e.g. using a rickshaw). These calculations integrated monthly repayments of the SHS and the expenditures for batteries repair. However, this study does not consider other types of repairs on SHS. Additional economic advantages include having access to light which enables individuals to work longer hours, to get a new job or to power their business for an extended period (Barman, Mahapatra, Palit, & Chaudhury, 2017; Gogla & Altai Consulting, 2018; Komatsu et al., 2011). As an example, in the context of Uganda, business opportunity is the third most important perceived benefits of SHS (Hirmer & Guthrie, 2017). Specifically, in the Indian context, economic benefits reveal an increased income for farming households and a more stabilised income through growing and selling diversified crops by using the surplus of kerosene for powering pumps for irrigation. In addition, SHS are said to enable farmers to harvest and process rice fields at night (Mishra & Behera, 2016). However, such benefits might be country- or region-specific. For example, the tracking of 500 SHS in Uganda and Kenya did not result in improving existent businesses or starting new ones (Stokanovski, Thurber, & Wolak, 2017).

Social impacts linked to SHS include improved standards of living (Barman et al., 2017), especially for women (Mishra & Behera, 2016). With increased study duration (Barman et al., 2017; Komatsu et al., 2011), education is being promoted, and children can enjoy higher concentration and studying environment with a better lighting quality and free from kerosene odours (Komatsu et al., 2011). Mobile charging enables to increase the levels of interaction and social cohesion between individuals as well as to increase workforce mobility, as individuals can be more easily aware of working opportunities in different geographic areas (Mishra & Behera, 2016). In some cases, mobile charging is far from being negligible, as in the case of Uganda, it has been perceived as one of the main benefits of SHS (Hirmer & Guthrie, 2017). Finally, SHS enable to provide entertainment and culture as households get access to complementary appliances such as TVs (Komatsu et al., 2011; Mishra & Behera, 2016). SHS also reduce the number of accidents at home and lead to increase safety and security in general (Mishra & Behera, 2016). However, it seems that powering appliances such as TV and radios largely depends on the country, as research on the use of 500 SHS in western Uganda and western Kenya found that no TVs, radios or flashlights were powered by SHS (Stokanovski et al., 2017). Research in Ethiopia identified additional social benefits such as a greater autonomy of children, family life, security, flexibility and stress reduction (Müggenburg, Tillmans, Schweizer-Ries, Raabe, & Adelmann, 2012).

From a health perspective, SHS and SL enable the reduction of indoor air pollution by shifting from kerosene lamps to electric lighting sources (Barman et al., 2017; Obeng, 2013). From an environmental perspective, SHS are said to reduce pollution and mitigate climate change (Feron, 2016), even though the carbon intensity of SHS largely depends on the PV technology chosen as revealed by the research performed in India by Sandwell et al. (2016). Such environmental benefits remain valid for solar lanterns as they require less energy to manufacture and to run in comparison with kerosene lamps (Lighting Global, 2014). However, a low level of environmental awareness coupled with a lack of policy for proper disposal of such products compromise the environmental sustainability of off-grid solar PV systems (Feron, 2016). In addition, the environmental sustainability of pico products[7] is influenced by the design of products, the manufacturing of pico products with quality materials and components, the

[7] A pico product is solar kit with a solar panel smaller or equal to 10 Wp (Orlandi, Tyabji, Chase, Wilshire, & Vickers, 2016)

availability of repair and training guides, spare parts and repair kit (Hirmer & Cruickshank, 2014).

3.4 Waste volumes and end-of-life strategies

3.4.1 Regulations covering off-grid products

Sinha-Khetriwal, Kaddouh, & Magalini (2018) identified four relevant regulations for SHS and SL in India:

- Batteries Management and Handling Rules (2010)
- E-Waste Management Rules (2016)
- Hazardous and Other Waste Management and Transboundary Movement Rules (2016)
- Solar Photovoltaics Systems, Devices and Components Goods Order (2017)

Despite the existence of several regulations for Electrical and Electronic equipment and batteries, the regulations mentioned above do not fully cover SL and SHS. Indeed, the E-Waste Rules, which require manufacturers to provide a Producer Responsibility Organisation (PRO) to collect and channel e-waste to recyclers, do not mention solar products. However, as SHS come with additional appliances such as TV, fan, mobile chargers, these products fall under the E-Waste Rules. Concerning batteries, the Batteries Management and Handling Rules require lead-acid manufacturers, importers and dealers to ensure collection of end-of-life (EOL) batteries and environmentally sound recycling. However, these rules do not target Original Equipment Manufacturers (OEMs), which limit the application of the rules for batteries directly included in off-grid solar products. Moreover, these rules do not cover other types of batteries such as lithium-based batteries. The hazardous and other waste management and transboundary movement rules stipulate that exports of solar waste (EEE, battery packs and panels) needs a Basel notification. Lastly, the Solar Photovoltaics, Systems, Devices and Components Goods Order does not mention EoL strategies for off-grid solar products.

3.4.2 Waste estimates

The main components of off-grid solar products have highly differentiated lifetimes. Therefore, evaluating the volumes of end-of-life batteries, solar panels and luminaries as well as the year when they will first arise largely depend on the average lifetime of each product components. Table 4 presents the average lifetime of SHS and SL product components based on the results of Sofies' feasibility study (2018).

Table 4: Average Lifetime of SHS and SL product components

Product component	Average lifetime (years)
Lead-acid batteries	3-5
Lithium based batteries	5-7
Solar panels	10-15
Luminaries	10

Source: Sinha Khetriwal and Kaddouh (2018, p13)

Given the average lifetime of SHS and SL components, lead-acid batteries and lithium-based batteries will be the first waste streams to arise and in significant volumes, in comparison with solar panels. Table 5 presents the average annual volumes of waste as well as the year when the waste of 2015 sales will first arise.

Table 5: Waste Volumes Estimates for SHS and SL in India

Products	Average annual volumes of waste (t)	Year when waste of 2015 sales will first arise
	SHS	
Batteries (Li)	220-310	2019-2021 (first replacement round)
Batteries (Pb)	310-520	2017-2019 (first replacement round)
Solar panels	35-50	2024-2019
LEDs	0.5	
	SL	
Batteries (Pb)	140-200	2019-2021 (first replacement round)

Source: Sinha Khetriwal and Kaddouh (2018, p14)

3.4.3 Disposal patterns for SHS and SL

The feasibility study conducted by Sofies offers the best reference on the most likely disposal patterns of off-grid solar products. Table 6 resumes the following disposal pattern for SHS and SL.

Table 6: Disposal patterns of SHS and SL

Products	Under Warranty	Outside Warranty	EoL Strategy
SHS	For large organisations, the product is brought back to the manufacturers' warehouses through own circuits of distribution	No information available	No repair or reuse of complete SHS were identified even in the informal sector. Only solar panels can be repaired through one plant formally in Chennai and one informally in Delhi
SL	Default product is returned to manufacturers and fully replaced	No collection of the product by distributors	No refurbished solar lanterns were found in the informal sector. Not found in the informal sector for recycling because of low intrinsic value
Batteries	Sent back to manufacturers in case of defect	No collection of the product by manufacturers. No lithium-based batteries were found from solar products in the informal sector. Lead acid are traditionally collected by the informal sector, but no mention of solar specific batteries is available	Not found in the informal sector because of low intrinsic value

Source: Sinha Khetriwal and Kaddouh (2018)

As a conclusion, off-grid solar products and more specifically SHS and SL are two growing product streams on the Indian market, supported by the government energy policy, despite a recent shift to solar pump subsidies. The difference in the average lifetime of SHS and SL components is an environmental challenge as current disposal patterns reveal a low collection rate of such products and no existence of proper end-of-life management strategies. Lead-acid batteries and lithium-based batteries will be the first waste streams to arise, followed by solar panels. These waste streams are perceived as an economic opportunity by the IRENA (2019).

4 A conceptual framework for business model innovation to catalyse product life extension strategies

This chapter provides an overview of key literature in the field of inner loop circular strategies and business models. It is structured in two subsections which build the conceptual framework described in Section 4.3.

Section 4.1 focuses on:

1) Circular economy concepts, practices and rebound effects with a focus on India; and
2) Practices, drivers and barriers of repair, reuse, refurbishment and remanufacturing strategies with a focus on developing countries context and off-grid solar products.

Section 4.2 focuses on:

1) Business Models ontology from traditional to circular business models;
2) Business Models for repair, reuse, refurbishment and remanufacturing; and
3) Concepts and approaches of business model innovation and experiment.

Section 4.3 resumes the literature finding and describes the conceptual framework which guided data collection.

4.1 Strategies for extending product life in the circular economy

4.1.1 The circular economy as an alternative economic model

As an alternative to the "take, make, dispose" production and consumption economic model, the concept of Circular Economy (CE) initially emerged in the 1970s and has, since then, triggered a growing interest from academia and practitioners (Ellen MacArthur Foundation, 2015; Geissdoerfer, Savaget, Bocken, et al., 2017; Kirchherr, Reike, & Hekkert, 2017; Murray, Skene, & Haynes, 2017). The concepts of CE originate from other concepts such as the spaceman, the steady-state economy, the limits to growth, industrial ecology, cradle-to-cradle and eco-efficiency (Kalmykova, Sadagopan, & Rosado, 2018). Its main and original objective is to decouple economic growth from resource consumption. To do so, this new paradigm must "preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows", "optimize resource yields by circulating products, components and materials" and "reveal and design out externalities" (Ellen MacArthur Foundation, 2015, p5-7). The Circular Economy diverges profoundly from the linear economy as finite stocks of materials and renewables ones should be recovered and restored (i.e. in the technical sphere) or regenerated (i.e. in the biological sphere). While recovering, restoring or regenerating materials flows, the highest value of products and materials should be preserved. The Ellen MacArthur Foundation (2015) refers to the preference for the *inner loops*, which seeks to favour activities preserving the original use and complexity of a product. In addition, the number of times that material flows are circling should be maximised and this might require to *cascade* outputs materials flows across different industries as substitutes for virgin materials.

While many definitions of the CE exists, most of them usually refer to the CE as an economic model for reduction, reuse and recycling of products, materials and components (Murray et al., 2017). In more practical terms, the CE can be defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This regenerative system can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" (Geissdoerfer, Savaget, Bocken, & Hultink, 2017, p759). However, current definitions usually focus mostly on recycling aspects and miss the importance of adopting a system shift to ensure the transition to a CE (Kirchherr et al., 2017). In addition, the analysis of 114 definitions of the CE by Kirchherr et al. (2017) concluded that most definitions of the CE do not integrate sustainability aspects, and when they do, solely put the emphasis on economic and environmental aspects. Geissdoerfer, Savaget, Bocken, et al. (2017) went further by classifying the relationships between the CE and sustainability in three categories 1) the CE as a condition for sustainability, 2) the CE has increasing sustainability, or 2) the CE as a trade-off of sustainability.

Most of the CE literature includes numerous examples of China, as the country adopted a national development policy for the CE in 2002 (Kalmykova et al., 2018). Along with the Chinese example, the CE literature counts numerous case studies reports underlining the importance of the CE for economic development, the CE benefits, the prioritised sectors for implementing the CE and its potential for both developed and developing countries. The two main points discussed in the CE literature are the dimensions of the implementation of the CE (i.e. local, regional, national or transnational) and the types of sectors, products, materials and substances (Kalmykova et al., 2018). Examples of the implementation of the CE include eco-parks and industrial symbiosis at the regional level, national policy programs promoting the CE at the national level and UN institutions at the transnational level. The most important sectors for implementing the CE are the industries of electric and electronic equipment, textiles, furniture, textiles, packaging and tires. Actors driving the CE implementation are mostly consultancy firms, legislative and governmental bodies as well as NGOs (Kalmykova et al., 2018).

Beyond the promise of preserving resources and reducing primary production (Zink & Geyer, 2017), the circular economy offers numerous macro and micro benefits. Businesses are likely to experience high-cost savings due to material savings (estimated over a trillion US dollars globally), increased growth and competitive advantage (Ellen MacArthur Foundation, 2014). The circulation of material flows is likely to mitigate price volatility, increase businesses supply chains resiliency and innovation. While the circular economy represents an opportunity for businesses and national economies to gain competitive advantages, it is also an opportunity for job creation as remanufacturing and recycling are expected to provide a million entry-level and semi-skilled jobs globally (Ellen MacArthur Foundation, 2014).

However, potential rebound effects of CE activities might arise and offset the environmental benefits of such circular products and services (Makov & Font Vivanco, 2018; M. P. P. Pieroni, McAloone, & Pigosso, 2019; Zink & Geyer, 2017). Drawing a parallel from the energy efficiency rebound, Zink and Geyer (2017) created the terminology of circular economy rebound and identified two main rebound mechanisms. In the case where products are less qualitative or less desirable to consumers, secondary goods are not necessarily substituting the production of the given product. This mechanism is referred as the substitution mechanism. In addition, as secondary products are likely to be low-priced because of their inferior quality, the secondary product customers will save some income, which is likely to be spent elsewhere. This leads to what Zink and Geyer (2017) call the income effect. In the context of developing countries, the authors underlined the likelihood of these two mechanisms to be even more significant. Indeed, consumers are likely to increase their consumption further when their income increase and secondary products would not replace consumption of primary products because such products were not initially consumed. As an example of the CE rebound, Makov and Font Vivanco (2018) researched the rebound effect of smartphone reuse through second-hand markets in the United States. Based on mix method analysis, their findings indicate an average rebound effect of 29%

in a case of imperfect substitution. However, with different hypothesis and replicating calculations in other regions, they identified a potential rebound effect of 100%. Therefore, the study concluded to remain critical of the CE before further research on its rebound effect is being conducted. Both Geissdoerfer, Savaget, Bocken, et al. (2017) and Kalmykova et al. (2018) also drew attention to the growing need of measuring the impact of the CE. Kalmykova et al. (2018) specifically referred to Material Flow Accounting and Life Cycle Analysis as tools to spot the unintended consequences of the CE.

In the Indian context, the CE has been identified as a significant economic opportunity, estimated at 218 billion US dollars in 2030 and a potential 624 billion by 2050 (Ellen MacArthur Foundation, 2016b; Jain et al., 2018). Key sectors for circularity are the mobility and vehicle manufacturing, the construction industry, the agriculture and food industry (Ellen MacArthur Foundation, 2016b) as well as the electronics and electrical equipment industry (Jain et al., 2018). From a resource efficiency perspective, the solar photovoltaic sector was also identified by the TERI Institute as a significant industry for CE (Bhattacharjya & Kapur, 2019). Described as a business imperative by the Teri Institute (Bhattacharjya & Kapur, 2019), a CE would provide numerous economic, social and environmental benefits to India. Given the high dependency of India on resources (Bhattacharjya & Kapur, 2019), building a CE in India would secure material supply, drive material costs down and therefore provide cheaper products to Indian consumers. Following the development pathway for the CE designed by the Ellen MacArthur Foundation, India could reduce its GHG emissions by 23% by 2030 as well as reduce congestion and pollution (Ellen MacArthur Foundation, 2016b).

4.1.2 Extending product life through repair, refurbishment and remanufacturing

Favouring inner loop strategies to preserve the value, complexity, and the embedded energy and labour of a product can be achieved by repairing, reusing, refurbishing and remanufacturing a product (Bocken et al., 2016; Ellen MacArthur Foundation, 2015; Geissdoerfer, Savaget, Bocken, et al., 2017). These strategies, which are among the most widely applied circular strategies by practitioners (Dominish et al., 2018; Whalen, 2017), differ from one another based on the type of processes applied to the product as well as the remaining performance level of the product. Most of these strategies are not uniformly defined and are sometimes intertwined in the literature, which can lead to significant misunderstanding of the results from previous research. Therefore, despite not integrating reuse and repurposing within the scope of this thesis, this literature review will still present significant findings in link with reuse and repurposing business model and will follow the below definitions:

- *Repair* is defined as the process of "restoring a product to a sound/good condition after decay or damage" (Bocken et al., 2016, p311), "for its originally intended purpose" (Nasr & Russell, 2018).
- *Reuse* is using "a product again for the same purpose in its original form or with little enhancement or change (Ellen MacArthur Foundation, 2014, p72).
- *Repurposing* is "use of a product or material for different function than it was originally produced for" (WBSCD, 2018).
- *Refurbishment,* synonym in the literature of reconditioning (Ardente, Talens Peiró, Mathieux, & Polverini, 2018), is the "process of returning a product to good working condition by replacing or repairing major components that are faulty or close to failure, and making 'cosmetic' changes to update the appearance of a product, such as cleaning, changing its fabric, painting or refinishing it." (Ellen MacArthur Foundation, 2014, p72). When refurbishment is performed in an industrial setting, Nasr & Russell (2018) refers to *comprehensive refurbishment.*

- *Remanufacturing* is the "process of disassembly and recovery at the sub-assembly or component level. Functioning, reusable parts are taken out of a used product and rebuilt into a new one. This process includes quality assurance and potential enhancements or changes to the components." (Ellen MacArthur Foundation, 2014, p72). Nasr & Russell (2018) precise that remanufacturing is a standardised process taking place in an industrial setting.

These product life extension strategies, also called value-retention processes (Nasr & Russell, 2018), differ from one another because of differences in the level of disassembly, in the quality of the product compared to a new one, in the technological upgrade of the product (Sharma, Garg, & Sharma, 2016). While reuse, repair and refurbishment imply a limited amount of disassembly of the product, remanufacturing requires a complete one, as per the above definition. In addition, the quality of remanufacturing is supposed to be higher as the used components is built into a new product. However, the quality of a reused, repaired or refurbished product is necessarily inferior to a new product. Lastly, refurbishment and remanufacturing differ from any other life extension strategy as they require a technological upgrade. In addition, remanufacturing and comprehensive refurbishment takes place in a factory setting while repair and refurbishment do not.

In practice, reuse, repair, refurbishment and remanufacturing are performed on a large variety of products including electronic and electrical equipment, vehicles, furniture, small and large machinery etc. (Chaowanapong, Jongwanich, & Ijomah, 2018; Dominish et al., 2018; Sharma et al., 2016; Wieser & Tröger, 2018; Zlamparet et al., 2017). Repair and refurbishment are said to be more commonly applied strategies than remanufacturing (Türkeli, Huang, Stasik, & Kemp, 2019). Indeed, remanufacturing usually involves products (1) whose technology is unlikely to evolve drastically over time, (2) which contains subparts with longer lifetime than the product will be used for and (3) which will likely fail functionally (Chaowanapong et al., 2018; Matsumoto, Yang, Martinsen, & Kainuma, 2016).

In the specific case of solar products, repair, reuse, refurbishment, remanufacturing and repurposing still remain insufficiently explored by academia given the limited number of papers identified through this literature review. Indeed, Strupeit & Bocken (2019) noted that the literature currently misses a review of circular strategies within the solar PV sector. Given the size of the off-grid market in comparison with the solar PV market, the author assumes that it is not surprising that the analysis of circular strategies for off-grid solar products has not yet been conducted.

Focusing on solar PV uniquely, the existing circular strategies in the sector have been identified by Strupeit & Bocken (2019). Table 7 only resumes the strategies that can extend product lifetime through sharing, reuse, repair, refurbishment and remanufacturing. The literature review of Strupeit & Bocken (2019) emphasised the commonality of maintenance and repair services in commercial and utility-scale PV. However, such system servicing has not been developed to such an extent for residential PV. This difference can be explained by the lack of data available on the systems and its poor-quality in addition to difficult economics and differences in user behaviours. However, the research underlined that high-value components such as inverters are usually being repaired either on the field, or by OEM or a third party. Repair of defect modules is not financially viable given the current market and price decrease of PV modules. In terms of refurbishment, second-hand panels can be refurbished and act a spare part replacement of modules that are not manufactured anymore. The research concluded that the limited amount of PV available for refurbishment, the declining cost of modules and potential growing competition of new technologies as well as the unclear market value of used PV modules limit the possibilities to extend solar PV lifetime. Knowing about and under which the reuse of PV is financially and environmentally beneficial is still missing. While focusing specifically on service-based business models for solar PV, Strupeit and Bocken (2019) highlighted the yet limited role of these models in operationalising circular actions.

Table 7: Circular Strategies in the PV Sector

Strategy Description	Value chain stages			
	R&D and manufacturing	**Distribution and Installation**	**Use phase**	**End-of-life**
Prolong life through maintenance and repair and design for durability	Increase conversion efficiency of PV modules and inverters; develop building-integrated modules with multiple functions	Ensure selection of high-quality PV products and high- quality PV installation Ensure high-quality PV installation	Enable systematic monitoring & preventive maintenance Enable preventive and high-quality maintenance; minimize PV system downtimes	
Product reuse or redistribution	Design PV products for easy disassembly	Use PV products for second-life applications		Enable appropriate disassembly, collection and refurbishment of PV products to facilitate reuse
Product repair, refurbishment or remanufacture	Design PV products for easy disassembly and repair	Remanufacture products disused in other sectors for use in PV applications (e.g. EV batteries)	Use second-hand products/ components as spare parts	Enable appropriate disassembly, collection and refurbishment of PV products to facilitate reuse

Source: Own illustration adapted from Strupeit & Bocken (2019)

In the off-grid specific context and according to Cross & Murray (2018), recycling has been pushed as the primary EoL strategy in African countries without taking into account the existence of a complex repair and refurbishment economy. Such recycling strategies fail to account for social behaviours of off-grid solar products users. As an example, 65% of Kenyan users keep their broken off-grid solar system components at home as they still perceive value in it. However, among the existing literature on the topic, repair is one of the most discussed strategies for off-grid solar products and has been identified as one of the 40 sustainability criteria of greater concern for the sustainability of solar pico products (Hirmer & Cruickshank, 2014). Circular strategies in the off-grid solar include several models of repair and services. One on hand, the product can be returned to the distributor of the brand and repaired by technicians. Alternatively, repair can be performed by a third party which is specialised in one type of product repair instead of one type of brand repair. Otherwise, spare parts and repair guides can be provided publicly to customers to repair the product by themselves or by a third party (Gogla, 2019a). As an example, the organisation Solar Worx operating in Sub-Saharan Africa has trained each of its distributors for one to two months to perform repairs including product recalibration. For this, it ensures to make all spare parts down to the component level and appropriate tools available at the distribution level (Boldt, 2019). In the Indian context, another example is the project called "Localisation of Solar Energy though Local Assembly, Sale and Usages of 1 Million Solar Urja Lamps". This project aims to locally train local villagers to assemble, campaign, distribute and repair solar lamps ("Million SoUL," n.d.).

Despite a growing desire among local communities for off-grid solar products repair, numerous challenges on the market still arise (Lighting Global, 2016). These include: 1) low product costs making replacement cheaper than repair ; 2) components availability; 3) manufacturers' fear of revealing propriety information; 4) anti-tampering protections; 5) spare parts availability; 6) availability of appropriate repair tools; and 7) appropriate information for repair (Lighting Global, 2016). Several strategies can be adopted by off-grid solar OEMs and OESs to provide repair services and overcome such challenges. Table 8 presents a comprehensive overview of implemented or suggested strategies for repair and maintenance services based on an informal conversation with the Founder of Solar Worx on July 24th, 2019 and review of grey literature in the field. This table highlights that repair strategies would require original product manufacturers to design products for which standardised spare parts will be available over time on the markets.

Table 8: Suggested or implemented repair strategies for off-grid solar products

Repair Strategy *(problem)*	**Strategy Benefits**	**Strategy Pre-requirements**
Integrating a remote monitoring system into SHS *(lack of understanding of the system's performance)*	• Quickly and remotely identify broken components • Send trained technician to the household with the appropriate tools and spare parts needed, reducing the associated last-mile costs of servicing • Reduce future cost of operations of the system by lowering the transmission of data from every hour to every day	
Replacing the used or defect battery by a new one into SHS and SL *(End-of-life or malfunction of the battery)*	• Easy to install without prior knowledge in electronics	• Change in product design to easily access the battery and replacing it without damages • Compatible connector of the new battery
Slicing a new connector or removing the damage section of the wire *(Damaged pin, corroded pin, damaged circuit board connection)*	• Easy to perform without product knowledge • Need of simple tools	• High quality OEMs components are preferred vs low-quality ones • Availability of standards parts
Repairing circuit boards *(Broken electronic component, broken connector, broken circuit trace, corrosion)*	• No knowledge of product operation is needed for circuit board replacement • DC power plugs and jacks are standardised	• Mechanical switches are not standardised and should be available by OEM • Skill technician for repair of circuit traces
Repairing solar module *(Failure in the panel, in the junction box, or in the cord)*	• If the cable is damaged, repair only includes to remove the damage section and to introduce a new cable	• Repair in the junction box is only possible if the box is not sealed or encapsulated • Repair of the junction box depends on the technician skills and the availability of a replacement cord/ plug which is compatible

Source: Own illustration based adapter from Boldt (2019) and Lighting Global (2016, 2017)

In comparison with repair, refurbishment and remanufacturing are not currently discussed in the off-grid solar literature. For Felix Boldt from Solar Worx (2019), remanufacturing is extremely complex given that Solar Worx products are manufactured in Asia but distributed in Africa. However, even though Solar Worx is not performing refurbishment per se, the Founder identified the opportunity to reuse components from a used system for reassembly, which could then be sold at a discounted rate (Boldt, 2019). In addition, an informal conversation with Rowan Spear, research fellow and product designer of the Solar What?! project at the University of Edinburgh on August 8th, 2019 revealed that remanufacturing/refurbishment of a solar light and portable torch is currently being investigated (Spear, 2019). However, the strategy of repurposing of used batteries for solar applications seems to be more widely studied. Indeed, electric vehicles batteries could be used as a home storage solutions for photovoltaic electricity (Beverungen, Bräuer, Plenter, Klör, & Monhof, 2017). Mobile phones lithium-ion batteries can be used to power LEDs using a solar panel. PC power supply can also replace a standard charge controller in a small solar photovoltaic system (Bunthern et al., 2015; Kim et al., 2016; Rogers et al., 2014). In addition, Kim et al. (2016), explored the repurposing of uninterruptible power supply units replacing a classic inverter and used local automobiles batteries for storage batteries. The repurposing of batteries can generate electricity at low cost, provide new jobs and provide more sustainable sources of electricity (Beverungen et al., 2017). The lower environmental impacts mostly comes from the avoided battery production and depends on the energy efficiency of the repurposed batteries (Kim et al., 2016).

Despite the differences in repair, refurbishment and remanufacturing activities, these product life extension strategies share common challenges. Indeed, repair, refurbishment and remanufacturing significantly alter traditional aspects of business activities, including supply chains, market conditions, product design and business strategy. Such factors are presented in the following sections.

4.1.3 The role of circular supply chains

Supply chains need to be redesigned to make sure that products can be returned/collected. This aspect has been identified as the largest barrier for implementation of product life extension strategies (Vermunt et al., 2019)[8]. The process that returns used products and components in the supply chain for repair, remanufacturing and even recycling is called *reverse logistics* (Berssaneti, Berger, Saut, Vanalle, & Santana, 2019). Reverse logistics can be performed by the original equipment manufacturer (OEM), the original equipment supplier (OES) or an independent third-party organisation. To ensure repair, reuse, refurbishment or remanufacturing, organisations become highly dependent on suppliers of used products which may deliver products of unknown quality and volumes, and in unknown timing (Kissling et al., 2013; Matsumoto et al., 2016; Vermunt et al., 2019). To overcome such barriers, Vermunt et al. (2019) suggested influencing the quality of a returned product by developing close relationships with supply chain actors or by retaining ownership of the product. For the specific case of remanufacturing, Ostlin, Sundin, & Björkman (2008) identified different types of remanufacturer-supplier relationships to ensure used products returns. The manufacturer can remain the ownership of the product by renting or leasing a product instead of selling it. Alternatively, a product can also be returned voluntarily by a customer or can be returned to the OEM as a deposit or in exchange of credits. A customer could also have a remanufacturing service included in a service contract. Lastly, a customer' product could be returned to a remanufacturer which will perform the remanufacturing service and send the same product back to the original customer. In all these cases, supply chains are very dependent on the willingness of customers or core suppliers to give back their products. For example, in the cases of reusing, repairing and recycling electronic products, Malaysian customers' intention to return a product for reuse/repair/recycling were found to depend on customers' perceptions of the risks associated, their ecological knowledge and their perceived advantages to reuse/repair or recycling (Kianpour et al., 2017). In the specific case of India, customers' lack of willingness to return products in the case of remanufacturing has been clearly established by the research of Sharma et al. (2016). According to Sharma et al. (2016) and Mangla et al. (2018), barriers to implementing circular supply chains have been more investigated in research targeting developed country context than developing countries. To bridge this gap, Sharma et al. (2016)

[8] However, it is important here to note that the research context has been conducted in the Netherlands with 31 Dutch companies. A developing country context might have provided different results.

identified sixteen barriers to implement circular supply chains in India and the interconnection that exists between these barriers. Among all barriers, the lack of environmental laws and regulations and the lack of preferential tax policies for circular models were found as the key barriers influencing the implementation of circular supply chains. One additional fundamental aspects of supply chains for circular strategies in a developing country context lie in the role of the informal sector (Corwin, 2018).

For solar pico products, the establishment of reverse logistics to ensure product return is one of the four key criteria to ensure sustainability along the value chain (Hirmer & Cruickshank, 2014). For solar panels in the Indian context, recommended circular chain strategies in the PV industry include to strengthen and organise the used solar panels segment through specialised dealers or manufacturers to ensure to bring back used panels and sell them through organised channels (Arora et al., 2018).

4.1.4 The role of market demand and customers' perceptions

In addition to supply chains, Vermunt et al. (2019) identified customer resistance as the second biggest barrier for implementing product life extension strategies. Indeed, used products can be perceived as less fashionable and consumers are looking for non-standardised products (Vermunt et al., 2019). Products can even be perceived of lower quality (Chaowanapong et al., 2018; Dominish et al., 2018; Nasr & Russell, 2018; Wang, Zhang, Zhang, & S Jeeva, 2015). For repair, there is a general lack of research on what drives consumers to repair/refurbish their products (Ellen MacArthur Foundation, 2016a). In addition to a lack of consumer awareness (Ellen MacArthur Foundation, 2016a), customer perceptions of product' obsolescence also influence consumers' choice for repair versus replacement as identified in the case of mobile phones repair in Austria (Wieser & Tröger, 2018). The general literature findings remain valid in the Indian context, as the study of Sharma et al. (2016) highlighted the importance of negative customer perceptions about remanufactured products, quality concerns and a general lack of awareness about the availability of remanufactured products. Despite negative perceptions, this literature review underlined numerous benefits as remanufacturing provides new-like products, at a reduced price to new customer segments (Sharma et al., 2016). To overcome such barriers, warranty has been identified as a successful marketing strategy to reassure customers on the quality of remanufactured products (Alqahtani & Gupta, 2017). For the case of reuse of electrical and electronic equipment of information and communication technologies as well as large household appliances, controlling product safety, quality and performance was ranked as one of the key success factors for reuse of such products[9] (Kissling et al., 2013).

In the off-grid solar industry, the role of customer demand has also been highlighted by Rowan Spear, project manager of the Solar What?! project run by the University of Edinburgh. During an informal interview, Rowan highlighted the role of customers in supporting the development of repairable off-grid solar products, along with the role of industry and government. For repairability to become a purchasing decision, benefits of repairable and openable products should be communicated to the end customers (Spear, 2019).

4.1.5 The role of circular design strategies

The role of product design has repeatedly been discussed in the literature to ensure the transition to a circular economy (Bocken et al., 2016; Chaowanapong et al., 2018; Ellen MacArthur Foundation, 2016a; Wang et al., 2015; Wieser & Tröger, 2018; Zlamparet et al., 2017). Strategies to extend product life include design for maintenance and repair, design for upgradability and adaptability, design for standardisation and compatibility and design for dis-and reassembly

[9] In this context, Kissling et al. (2013) refers to used product sold by for profit and non-profit organisations.

(Bocken et al., 2016). Design for maintenance and repair refers to a product design that ensures ease of servicing tasks of maintenance and repair on a product. To take into consideration the possibility for a product to expand or to be modified in the future, a product can be designed to be further upgraded. Lastly, the lifetime of a product can be extended if the product can be easily dismantled and reassembled and if the products' components are standardised and can easily fit other products as well. In the specific context of product remanufacturing in India, a lack of designing for repairability and disassembly, cleaning, replacing and reassembling has been identified as an essential roadblock (Sharma et al., 2016). Product design is directly influenced by market demand requiring non-standardised products (Vermunt et al., 2019).

The role of circular design strategies has also been highlighted by the solar PV and off-grid solar literature. According to Strupeit & Bocken (2019), closing product, component and materials loops for solar PV requires solar panels redesign. In the Indian context, the design stage of solar PV has also been identified to be of crucial importance for repair, refurbishment remanufacturing, dismantling and extending product use life (Arora et al., 2018). Innovative examples include Apollon Solar which has designed an easy-to-dismantle solar module called New Industrial Cell Encapsulation (NICE). The technology interconnects the solar cells together instead of soldering them together. The module can also be easily opened, and components can be repaired or replaced. In addition, research is currently conducted to develop an automated system which could identify the defect cells to be repaired. An additional example is Solergy, an US-based organisation, which has designed an upgradeable solar PV system to extend the service life of a panel from 25 years to 40 years by upgrading the cell technology over time. According to Arora et al. (2018), achieving resource efficiency in the solar PV industry requires standardised and easily dismantled product designs.

From an off-grid solar market perspective, the industry association GOGLA identified design strategies for durability and design strategy for ease of maintenance and repair as the two dominating design approaches in the sector (Gogla, 2019a). Design choices to ease the repair off-grid product should follow the below guidelines (Lighting Global, 2017):

- screws hold the product together and not glue.
- screws should be of one type or should be obviously different from one another.
- cover fixing screws should be indicated by a visible symbol.
- glued or taped components should be easy to break without damage to the product.
- single use fixing clips should not be used.
- if security screws are used for a consumer not to open the unit, they should accessible and should be a standard security hex or security torx.

Organisations designing their product for repair include for example Azuri, an SHS provider of in sub-Saharan Africa. The organisation has changed the design of its SHS junction box to enable an easy cable replacement, thereby reducing repair time and cost. In addition, the project *Solar What?!* run by the University of Edinburgh has developed a solar light and portable torch which is compatible with solar panels between 5 to 30 volts. In addition to a focus on compatibility design, *Solar What?!* is composed of three sections held by screws which can be easily removed with standard tools. The lithium-ion standard battery can be fully replaced without damaging the printed circuit board (The University of Edinburgh, n.d.). In less than 3 minutes, the unit can be disassembled using a simple Philips head screwdriver (The University of Edinburgh, 2019). Rowan Spear from the Solar What?! project mentioned the challenging preconceived duality in the industry between designing a long-lasting product and designing a product which can be easily opened and repaired. Some off-grid solar product brands feared that making a product easy to repair will damage the intellectual property as well as the brand identity of the product. However, the prototype made by the *Solar What?!* project is proving that there is no conflict between durability and sustainability (Spear, 2019). In addition, based on the principals of Design for Environment and Design for Disassembly, the University of Edinburgh and the Silicon Valley Toxic Coalition created an off-grid solar scorecard to evaluate the repairability, recyclability and spare part availability of a pico-solar product (University of Edinburgh & Silicon Valley Toxics Coalition, 2016). Despite examples of successful implemented design for repair and useful tools, most common off-grid manufacturers do not consider design strategies for repair, refurbishment and remanufacture and some might even deliberately plan for products obsolescence (Cross & Murray, 2018; Salim et al., 2019).

According to Wastling, Charnley, & Moreno (2018), circular design strategies have been too focussed on physical aspects of products without taking into consideration the importance of a design that accounts users' behaviours. This observation seems to be supported by Feron (2016) as the researcher argues that designers of off-grid PV systems (often from developed countries) have a poor understanding of users' behaviours. Consequently, the lack of understanding of users' behaviours of off-grid solar products might also influence off-grid solar product design and its repairability, standardisation, compatibility as well as dis-and reassembly.

4.1.6 The role of knowledge and technology

Given the labour intensity of remanufacturing activities, the remanufacturing literature mostly highlights the availability of technically skilled workers and technology as key drivers of such strategy (Chaowanapong et al., 2018). However, in the off-grid solar literature, factors of knowledge and technology appear more crucial for repair and maintenance. Indeed, the lack of local repair technicians has been identified as compromising the sustainability of off-grid solar products (Hirmer & Cruickshank, 2014; Mishra & Behera, 2016; Nathan, 2014). As an example, in the context of Assam in India, the lack of human resources impacted the viability of SHS specific institutions to offer maintenance services, spare parts, awareness of the system as well as training of local technicians (Barman et al., 2017). In addition to technicians training, the literature about off-grid solar products advocates for customer education to operate and maintain their off-grid solar products. Indeed, understanding product functionality, operation and maintenance is crucial to facilitate repair and maintenance of off-grid solar products (Barman et al., 2017; Brooks & Urmee, 2014; Mishra & Behera, 2016; United Nations Foundation & Sustainable Energy for All, 2019). As an example, the research conducted by Barman, Mahapatra, Palit and Chaudhury (2017) in four districts of Assam, India found out that 28.9% of the solar home systems were functional, 62.3% were working with minor faults and 8.8% were having major faults or being non-functional. Interestingly, 7.22% of SHS were non-functional because of complete battery damage. In this context, the reason lies in a poor user understanding of the system, which led the user to remove the charge controller and directly connect the battery to the luminary. Brooks & Urmee (2014) confirmed this lack of customer's understanding in the context of the Philippines. Therefore, appropriate users' and technicians' training using the right content at the right time is a crucial factor to successfully implement decentralised solar PV systems in rural areas. To reflect the importance of this point, Arora et al. (2018) recommended capacity development actions such as the training of personnel in resource-efficient processes and techniques. Lastly, to the author's best knowledge, literature highlighting the role of knowledge and technology for refurbishment appears to be lacking. Given that off-grid solar products repair are said to require specific skills, it is reasonable to believe that this also applies to refurbishment, particularly given the high degree of product disassembly in refurbishment (Sharma, Garg, & Sharma, 2016).

4.1.7 Additional barriers for repair, refurbishment and remanufacturing

Even though Vermunt et al. (2019) did not identify additional major barriers specific to the product life extension strategy beyond market and supply chains factors, additional literature offers a different perspective. The literature on such factors seems to be more abundant in the remanufacturing case in comparison with repair and refurbishment. Factors including business operations and organisational factors, financial and policy factors also seem important in a developing country context.

First of all, repair, refurbishment and remanufacturing affect the current business operations. In the context of China, remanufacturing has been seen as a business strategy opportunity because of material cost savings, production time reduction, brand protection and customer loyalty increase (Wang et al., 2015). In addition to the opportunity to sell products to different market segments, remanufacturing operations can generate a positive image for an organisation (Chaowanapong et al., 2018). Despite high-profit margins and raw material cost savings, Matsumoto et al. (2016) noticed a lack of knowledge and motives of OEM to engage with product remanufacturing. In addition, operations need to be redesigned as the organisation deals with uncertainties about product quality, quantity and timing. Matsumoto et al. (2016) identified a need to conduct more research on several topics such as operations forecasting, product scheduling, capacity and production planning and inventory management for remanufacturing. In the Indian context, major barriers for remanufacturing include the largely unorganised remanufacturing sectors, the lack of proper remarketing strategies, the lack of cooperation with OEMs, low willingness of dealers to sell cheaper remanufactured products as well as the threat of counterfeit products (Sharma et al., 2016).

Secondly, institutional barriers related to policy highly varies from one country to another. While policy factors were found to be the least important factor for remanufacturing activities in Thailand (Chaowanapong et al., 2018), they were considered as one of the most driving and hindering factors for remanufacturing in China (Wang et al., 2015). In India, the absence of remanufacturing policies and standards, as well as a general lack of government support, reveal numerous roadblocks for remanufacturing (Sharma et al., 2016). In the context of reuse of electronic equipment, Kissling et al. (2013) identified a lack of legislation to incentivise or enforce access to reused products. No literature has been identified by the author linking off-grid solar products repair, refurbishment and remanufacturing with policy barriers.

Lastly, the existence of international standards such as the Lighting Global quality assurance program has worked against the repairability of off-grid solar products (Cross & Murray, 2018). Indeed, the research conducted by Cross & Murray (2018) brought to light the challenges faced by manufacturers to comply with the IFC standards while ensuring the affordability of their products and ensuring one to two years of warranty. Their research highlighted that even though an off-grid product meets the Lighting Global Standards, the location of the battery in the product, the battery type and the choice of screws will significantly influence users' ability to extend the product life after the end of the warranty period.

4.2 Operationalising the Circular Economy with Business Models

To mainstream the circular economy, changes at the micro, meso and macro societal levels are required (Ghisellini, Cialani, & Ulgiati, 2016). The Ellen MacArthur Foundation (2015) identified circular product design and product, reverse logistics, enabling factors and business models (further referred to *circular business models (CBM)*) as the four levers to accelerate the transition from a linear to a circular economy. Given the importance of business models in ensuring a transition to a CE, Kirchherr et al. (2017) argue that business models should be emphasised in CE definitions. The following sections present an overview of key concepts on business model ontology, business models specifics for repair, reuse, refurbishment and remanufacture as well as business model innovation and experimentation.

4.2.1 From Traditional Business Model to CE Business Model Theory

Even though there is not one single definition of business model commonly agreed upon in the literature (Zott, Massa, & Amit, 2011), most research commonly understand business model as "the rationale of how an organisation creates, delivers, and captures value" (Osterwalder, Pigneur, & Clark, 2010, p14). To create, deliver and capture value, Osterwalder et al. (2010), designed the Business Model Canvas, composed of nine blocks. It requires to define what is the *value proposition* of the business, meaning what the rationale for customers to choose one organisation's products or services over another is. This value proposition should seek to meet specific *customer segments*' needs and problems. Value propositions depend on the organisation's physical, intellectual, human and financial *resources*. Delivering the designed value proposition requires *channels* for communication, distribution and sales as well as performing *key activities* and *maintaining customer relationships*. However, some activities can be outsourced or performed outside of the organisation, through *key partnerships*. These can take several forms and usually aim to achieve economies of scale, risk reduction and/or acquisition of key resources or activities beyond the organisation. To capture value, the organisation needs to establish a stable financial model where *revenue streams*, resulting from the delivery of the value proposition to the targeted customer segments are captured. In parallel, creating and delivering the value proposition(s) come with specific fixed and variable costs (i.e. *the cost structure*).

These nine building blocks were simplified by Richardson (2008) in three pillars: value proposition, value creation and delivery and value capture. This definition of a business model will be the one followed in this research. In comparison with Osterwalder et al. (2010), both Richardson (2008) and Teece (2010) highlighted the role of the business model as a tool to execute the organisation's strategy. Therefore, the value proposition dimension also includes the definition of a strategy for the organisation to sustain its competitive advantage. Moreover, the dimensions of value creation and delivery emphasise the position of the organisation within its value network for suppliers, partners and customers. With a slightly different taxonomy, Lüdeke-Freund (2009) developed a four-pillar approach to a business model framework. In this model, value creation and delivery were differentiated as customer interface and infrastructure management, leading to a business model framework composed of four components (i.e. value proposition, customer interface, infrastructure management and cost structure and revenue model). The design of the presented business model frameworks should support a plethora of possibilities to conduct a business logically. However, Teece (2010) argued that a business model should deliver a value proposition to meet specific needs which are not easily replicable by competitors and heavily relies on assessing both internal factors and external factors.

The traditional business model theory has been influenced by the development and growth of other concepts such as sustainability and circular economy, leading to the taxonomy of *sustainable business models* (SBM) and *circular business models* (CBM). Despite not being consistently defined within the literature (Pieroni, Pigosso, & McAloone, 2019), this research understands a sustainable business model as a "business model that creates competitive advantage through superior customer value and contributes to the sustainable development of the company and society" (Lüdeke-Freund, 2010, p23). What makes a sustainable business model differ from a traditional one is the integration of the three dimensions of sustainability in the value proposition including measurable economic, social and environmental value (Boons & Lüdeke-Freund, 2013). Such integration leads to the creation of value not just for customers, but for a multitude of stakeholders including customers, investors and shareholders, employees, suppliers, partners, the environment and society (Lenssen, Bocken, Painter, Ionescu-Somers, &

Pickard, 2013). To align existing business models tools and frameworks with sustainability aspects, Osterwalder et al. (2010) added new categories including social and environmental costs and social and environmental benefits into the previously described Business Model Canvas. Integrating sustainability aspects into an existing framework is also the strategy followed by Lüdeke-Freund (2009). Indeed, the author integrated sustainability aspects within the four pillars already described above (i.e. value proposition, customer interface, infrastructure management, financial aspects) and by creating a fifth pillar entitled "the non-market business pillar". This pillar should list all non-market resources used by the organisation as well as the activities related to corporate sustainability. Despite the redesign of existing tools, new tools and frameworks are also being designed to better integrate sustainability aspects. One of the most commonly referred types of BM in the literature are the eight sustainable business models archetypes presented by Bocken, Short, Rana, & Evans (2014). The systematic review of business model innovation for sustainability and circularity performed by Pieroni et al. (2019) revealed that tools and frameworks are diverging from the classic approach of business models both in the boundaries of business models but also in its representation.

Although mostly discussed by practitioners in grey literature, business models for circularity are still a recent phenomenon in academic literature (Lüdeke-Freund, Gold, & Bocken, 2019; Pieroni et al., 2019). With the objective to create a unified understanding of CBM Nussholz, 2017 (p12) defined CBMs as "how a company creates, captures, and delivers value with the value creation logic designed to improve resource efficiency through contributing to extending the useful life of products and parts (e.g., through long-life design, repair and remanufacturing) and closing material loops". As within the business models and sustainable business literature, academic research has designed numerous archetypes and frameworks for approaching CBMs. This literature review will provide some of the most frequently presented archetypes and frameworks in literature. Lewandowski (2016) extended the classic Business Model Canvas of Osterwalder et al. (2010). From nine building blocks, the Circular Business Model Canvas includes eleven pillars with two pillars: the *take back systems* and the *adoption factors*. As the principles of the Circular Economy aim to circulate materials, components and products through both technical and biological cycles, businesses need to ensure to receive back products, components and materials. To do so, businesses might have to engage in take-back management, collection and incentivising customers to return their products. For Lewandowski (2016), such activities require new partnerships, channels and new customer relationships and should, therefore, be a separate pillar. Given numerous factors hindering the adoption and implementation of circular business models, Lewandowski (2016) also recommends identifying the internal and external factors that enable the adoption of circular strategies.

To adopt and implement the circular economy principles into business practice and strategy, companies need to rethink the way they create, deliver and capture value (Lüdeke-Freund et al., 2019). For Bocken et al. (2016), these strategies are categorised into slo*wing or closing resource loops.* To slow the needs of resources, businesses can offer the functionality of a product through a service, without transferring the ownership to the customer. This model called *access and performance model* includes examples such as car-sharing or leasing phones. Companies can also *extend product value* by collecting used products, components to remanufacture them. If products are originally manufactured to be repairable and durable, the average lifetime of a product would be extended (i.e. *the classic long-life model).* Another strategy is to encourage consumers to reduce their consumption by ensuring that their product can be upgraded, be repairable and that the organisation does not promote consumerism through its marketing strategy and sales (i.e. the *sufficiency model).* If the life of used products, components and materials cannot be extended, they can still be circulated to turn into new forms of value (i.e. *extending resource valu*e). When such products, components and materials are residual outputs from a manufacturing process fed into inputs for another process, this business strategy is named *industrial symbiosis.* With a slightly different taxonomy, Lüdeke-Freund et al. (2019) identified six major CBMs pattern: repair and maintenance, reuse and redistribution, refurbishment and remanufacturing, recycling, cascading and repurposing and organic feedstock business models. Through a review of 140 circular business model cases, Whalen (2017) sought to identify the dominating circular business models implemented by companies. Her research highlighted that the most recurrent CBMs are a*ccess and performance model*, *extending product value* and *extending resource value*.

The adoption of circular business models varies greatly from one organisation to another. According to Urbinati, Chiaroni, & Chiesa (2017), the adoption of circular business models depends on the *customer value proposition and interface* (i.e. how circularity is integrated in the customer value proposition and how it affects the organisation's competitive landscape) and on *the value network* (i.e. the organisation's internal activities and its relationships with suppliers and partners). Based on a low or high score on these two dimensions, a business engaging with circularity can be classified as:

- Fully circular: businesses which have adopted circularity both outside of the organisation and inside;
- Upstream circular: Internal activities and relationships integrate circularity, but such circularity elements are not visible to the consumer through pricing or communication;
- Downstream circular: adoption of circular economy in the customer value proposition and interface but not integrated into the internal activities and relationships of the business.

In the research performed by Urbinati et al. (2017), business size and age, type of industry and geography did not influence the adoption of a fully circular, upstream or downstream circular business models. However, the commitment of management did. Usually run in parallel to linear business models (Whalen, 2017), fully circular businesses are far from being sufficiently diffused according to Urbinati et al. (2017). For Vermunt et al. (2019), they remain very new and still lack credibility and legitimacy in the business field.

4.2.2 Repair, Reuse, Refurbishment and Remanufacture Business Models

This section aims to provide a comprehensive overview of how business models for repair, refurbishment and remanufacturing differ from other types of circular business models, following Richardson's business models framework of value proposition, value creation and delivery and value capture.

Value Proposition

The value proposition for CBM has been defined generically as a proposition "to create a product/service which uses a circular strategy to create value" (Nussholz, 2017, p12). As circular strategies differ from one another, so do their value propositions. Therefore, a comparison of value propositions in Bocken et al. (2016) and Lüdeke-Freund et al. (2019) frameworks is necessary to offer a more detailed view on value propositions for extending product life strategies. Both Bocken et al. (2016) and Lüdeke-Freund et al. (2019) acknowledged the environmental value in extending product life by exploiting the residual value of products in the case of repair, and by substituting new products and virgin materials in the case of reuse. In the case of refurbishment and remanufacturing, the environmental value proposition is less evident as the environmental impact will depend on the energy consumption of refurbishment/manufacturing processes as well as the energy efficiency of the product (Lüdeke-Freund et al.,2019). Moreover, both studies placed a strong focus on offering an affordable/ reduced price and almost "as new" product, especially for the case of refurbishment and remanufacturing. Only Lüdeke-Freund et al. (2019) spotted repairing strategy as a way to strengthen customer relationships, enhance reputation, prolong customer experience of their products and reduce social externalities. The positive impact on society from extending product life strategies is not specified in the literature, beyond the social value proposition of "maximizing product and service value for society well-being" (Geisendorf & Pietrulla, 2018,p9).

Value creation and Delivery

When product life extension strategies are vertically integrated into a business' operations, Nasr & Russell (2018) underlined the potential of customer services to reinforce customer relationships and even attract new customer segments. In the off-grid solar industry, increasing the service life of a product through repair support the organisation into building a strong customer relationship (Lighting Global, 2016). More precisely, Lüdeke-Freund et al. (2019) provides a clear description of potential customer segments for BMs of repair and maintenance, reuse and redistribution and refurbishment and remanufacturing. As both of these strategies are supposedly leading to price reduction, cost-conscious customers are identified as targeted customers for all of these business models. In addition, business-to-business suppliers in the case of repair and refurbishment/remanufacture, customer to customer suppliers were identified. Pearce (2009) provided even further guidance by identifying six potential customer segments for refurbishment, remanufacturing and recycling: 1) customers who want to retain a product because of the important role of this product in a current process of production; 2) customers who do not wish to re-specify or recertify a product; 3) customer who will have a low utilisation of the product; 4) customers wishing to enjoy the use of a product which has been discontinued; 5) customers who simply want to gain the benefits of using their products longer; and 6) environmentally conscious customers.

Partners and stakeholders identified to ensure the delivery of repair, reuse, refurbishment and remanufacture services include manufacturers and service providers (Lüdeke-Freund et al., 2019) also called OEMs and "gap exploiters" by Bocken et al. (2016). In the specific case of reuse and refurbishment, collectors of products/components/materials are essential partners as well as retailers for reuse business models (Lüdeke-Freund et al., 2019). However, it is worth noting that customers, investors, shareholders, employees, suppliers, the environment and society, which were identified as crucial stakeholders for sustainable business models (Lenssen et al., 2013) are not specified in the BM literature on product life extension.

The set of key activities for extending product life models differ in complexity. While repair mostly requires providing services and results, reuse and refurbishment/remanufacture include take-back activities and also providing used products. Connecting suppliers and customers is, according to Lüdeke-Freund et al. (2019), a unique activity of reuse and redistribution business models. Despite a clear identification of most of the circular business model components of value creation and delivery, key resources and capabilities and channels were not specified by the literature.

Value Capture

Delivering repair, reuse, refurbishment and remanufacturing generate new costs such as labour costs, costs associated to the activities of repairing, maintenance and control, transportation and logistical costs (in the case of reuse and refurbishment) (Lüdeke-Freund et al., 2019). However, product life extension strategies might also reduce costs. As an example, manufacturers of vehicle parts, heavy-duty equipment parts and industrial digital printers experienced between 15 to 23% reduction of production costs due to avoided material inputs and energy costs of processing (Nasr & Russell, 2018). This can directly transfer into higher margins for manufacturers (Nasr & Russell, 2018). In addition to reduced costs, additional revenues streams are also generated through the payment of repair services and products sales for reuse, refurbishment and remanufacturing (Lüdeke-Freund et al., 2019).

4.2.3 Business Model Innovation and Experimentation

Business Model Innovation

Business Model Innovation (further described as BMI) refers to the "designed, novel, and nontrivial changes to the key elements of a firm's business model and/or the architecture linking these elements" (Foss & Saebi, 2016, p216). Consequently, BMI enables an organisation's BM to be transformed into another one (Geissdoerfer, Vladimirova, & Evans, 2018, p409). For Wirtz, Göttel, & Daiser (2016), BMI is a another form of innovation, along with product/service and process innovation. The extensive literature review performed by Foss & Saebi (2016) brought into light the four major research streams around the concept of BMI: its conceptualisation, its organisational change processes, its outcomes and its performance implications. For Wirtz et al. (2016), design and process, as well as, drivers and barriers are also significant aspects of research on BMI.

The degree of innovation of a business model, also called BMI intensity by Wirtz & Daiser (2017) varies from moderate to radical innovation, depending on how new the changes are to the firm and the industry and if the changes are categorised as architectural or modular (Foss & Saebi, 2016, p216). An organisation's business model can be a natural and gradual process over time (i.e. *the evolutionary BMI*), or it can also be focused on one specific area of the BM which brings novelty to the industry (i.e. *the focused BMI*). When changes to a BM are done to adapt to new market circumstances, the BMI is said to be *adaptive*. Lastly, when changes disrupt market conditions and are bringing novelty into the industry, the BMI is *complex* (Foss & Saebi, 2016).

Despite a lack of research into what drives BMI to occur (Foss & Saebi, 2016; B. Wirtz et al., 2016), this innovation type can be triggered by external factors such as economic pressure and customer satisfaction (Stampfl, 2016) but also stakeholders demand and technology opportunities (Foss & Saebi, 2016). In addition, internal factors including strategic changes, technology and product change, as well as top management commitment, can trigger BMI (Stampfl, 2016). The process of BMI largely depends on the internal capacity to react to opportunities and threats, seize opportunities and remain competitive (Foss & Saebi, 2016). BMI occurs in an environment influenced by macro-factors such as globalisation, technology, industry/market shifts and regulatory/economic issues and micro factors, such as customer needs, product innovation, competition and firm dynamics (Wirtz & Daiser, 2017). This is why Kringelum and Gjerding (2018) identify BMI as contextual.

Several authors in the literature have detailed the process for business model innovation (Geissdoerfer, Savaget, Bocken, et al., 2017; Pieroni, McAloone, & Pigosso, 2019; Stampfl, 2016; Wirtz & Daiser, 2018). For Stampfl (2016) and Pieroni et al. (2019), sensemaking (i.e. sensing a divergence between its product/service offer and market requirements) is the first step of BMI. Then, the current BM will be refined and adjusted (Stampfl, 2016) to seize identified opportunities (Pieroni et al., 2019). However, many steps are required to perform such adjustment (Geissdoerfer, Savaget, & Evans, 2017; Wirtz & Daiser, 2018). After analysing the current BM (Wirtz & Daiser, 2018), new ideas on the mission of the BM and different customers scenarios can be generated. Such ideas would then be conceptualised using the BM canvas (Geissdoerfer, Savaget, & Evans, 2017) and tested for their feasibility (Wirtz & Daiser, 2018). Authors agreed that prototyping several BMI alternatives and testing them in field experiments is a required step. Geissdoerfer, Savaget, & Evans (2017) go further in detail by evaluating all the interactions between the different components of the BMI. Finally, testing the new BM through a real pilot on the market before full implementation is recommended. After launch, the BM would need monitoring and controlling, as adjustments might be required to ensure a sustainable transition and competitiveness (Geissdoerfer, Savaget, & Evans, 2017; Stampfl, 2016; Wirtz & Daiser, 2018). However, the BMI process is not a formal checklist for business model innovation practitioners. On the contrary, this process should be adapted to businesses' needs and is iterative. Therefore, the organisation might not perform all steps or might repeat them several times (Geissdoerfer, Savaget, & Evans, 2017; Wirtz & Daiser, 2018). However, BMI is complex to perform and involves risks (Wirtz et al., 2016) as anticipating the real performance of a BM in the market is difficult (Foss & Saebi, 2016). Uncertainties mostly arise from changes in technology, market dynamics, management, timing, corporate changes and employees reluctance (Stampfl, 2016). Therefore, BMI does not necessarily lead to better market performance (Wirtz et al., 2016).

Sustainable and Circular Business Model Innovation

Recently, the literature around BMI expanded by integrating sustainability and circularity dimensions (Pieroni et al., 2019). Sustainable BMI (further referred as SBMI), has been defined by Geissdoerfer et al. (2018, p406) as "the analysis and planning of transformations to a more sustainable business model or from one sustainable business model to another". This systematic and comprehensive literature review on the topic identified four types of SBMI: the creation of a sustainable start-up, the transformation of an unsustainable BM into a sustainable one, the diversification of BMs in one organisation by adding an existing sustainable BMl, the identification, acquisition and full integration of SBMI in the organisation. Components of collaboration and cost and revenue structures are likely to be changed, as sustainability requires a participatory approach and the generation of social and environmental value along with economic value (Pieroni et al., 2019). However, the integration of sustainability into BMI lead to specific challenges including the difficulty to co-build economic, environmental and social benefits, the rigidity of company mindsets, guidelines and norms and its potential reluctance to allocate resources along with the complexity of integrating innovative technology and engaging with external stakeholders.

BMI with a CE orientation is a very recent field of research (Diaz Lopez, Bastein, & Tukker, 2019) deserving further expansion (Pieroni et al., 2019). Engaging with CBMI mostly originates from resource efficiency, resource effectiveness, economic growth and superior customer value reasons (Pieroni et al., 2019). Despite the CBMI process being similar to the one described by the BMI classic literature (Antikainen, Aminoff, Kettunen, Sundqvist-Andberg, & Paloheimo, 2017; Antikainen & Valkokari, 2016; Bocken, Strupeit, Whalen, & Nußholz, 2019; Guldmann, Bocken, & Brezet, 2019) authors identified that CBMI requires a holistic and dynamic process which integrates aspects of human behaviour (Pieroni et al., 2019), customers and stakeholders' perspectives (Uusitalo & Antikainen, 2018) and co-creation and collaboration processes with stakeholders (Bocken et al., 2019). The need to adopt a system perspective for CBMI requires a further understanding of the business ecosystem level, an analysis of sustainability costs and benefits and frequent evaluation of the sustainability and circularity components (Antikainen & Valkokari, 2016). To perform such a process, the literature either strongly highlights the lack of tools for practitioners for CBMI (Antikainen et al., 2017; Guldmann et al., 2019; Pieroni et al., 2019) or estimate that existing tools do not sufficiently integrate interdisciplinary approaches (Bocken et al., 2019).

The innovation made to a BMI with a CE orientation are likely to include take-back management and reverse logistics, service-oriented schemes, collaboration and new financial models (Pieroni et al., 2019). More specifically, Diaz Lopez et al. (2019) identified which business model changes are likely to occur if an organisation is to implement resource efficiency measures. For measures such as circular economy, cradle-to-cradle and industrial symbiosis, the changes are likely to affect partnerships, activities and key resources, as well as, channels and customer segments. Moreover, for resource efficiency measures, such as product-service systems, product lease, product pooling, pay-per-service unit and take-back management, the changes are likely to be related to customer segments, channels and relationships components. In addition, the degree of change (i.e. how incremental or radical the change is) and the scope of change (i.e. how many actors are included in the change) were researched by Diaz Lopez et al. (2019). Renting and sharing products and take back management are measures with the highest degree of change while circular economy measures and cradle-to-cradle lead to the highest scope of change. Product-as-a-service is considered as the strategy with the higher degree and scope of change. Barriers for the implementation of CBMI by practitioners include the difficulty to evaluate hypotheses due to CE strategies' timespan and the level of resources risked before market validation for complex innovation such as the product as a service model (Linder & Williander, 2017). Lack of time, resources, difficulty to include external stakeholders, participation are challenges faced by practitioners when conducting CBMI.

Experimenting in BMI, SBMI and CBMI

Despite its overall under-exploration in the literature (Bocken & Antikainen, 2018), the role of experimentation has specifically been emphasised in the SBMI and CBMI literature (Bocken, Schuit, & Kraaijenhagen, 2018; Bocken & Antikainen, 2018; Weissbrod & Bocken, 2017). Identified as an essential capability for innovation, business experimenting is defined as a way to "learn and improve business model innovation activities with limited risks and resources through continuous and collective learning with stakeholders" (Bocken et al., 2018, p1). Experimentation for the CBMI can either be conducted as an intuitive process using the limited resource and information available (i.e. effectuation), as a faced paced and customer-centric approach with ideation, prototypes, data collection etc., with design thinking approach or using the circular business experiment cycle (Bocken & Antikainen, 2018). This cycle initially developed by Bocken, Schuit and Kraaijenhagen (2018) seeks to evaluate the purpose of the organisation, to conduct experiments of the value proposition, value delivery, value creation, value captured and to test all assumptions through a field experiment. In practice, CBMI experimentation enabled the acceleration of sustainable change in both large and small organisations (Bocken, Weissbrod, & Tennant, 2016; Bocken et al., 2018) and a way to overcome knowledge and technology barriers of CBMs (Vermunt et al., 2019). It creates internal and external engagement, reduces investment risks, enables to test assumption on all the business model components, but requires strong collaboration with stakeholders and numerous sustainability verifications along the way (Bocken et al., 2018).

4.3 Summary & conceptual framework

Knowledge gaps in the literature

In summary, the CE holds numerous promises for the development path and growth of developed and developing countries. As one way to achieve a more circular economy, extending the average lifetime of products through repair, refurbishment or remanufacturing has been widely addressed by academics and already applied by practitioners. However, despite academics and practitioners' growing interest, extending product life strategies are mostly studied in developed countries contexts. Consequently, there is a need for research of inner loop circular strategies in a developing country context, in which repair and reuse economies are often already well established (Corwin, 2018; Cross & Murray, 2018). In addition, this literature review brought to light a limited amount of research linking the market segment of off-grid solar products with circular strategies. Therefore, there is a significant gap in research on repair, refurbishment and remanufacturing strategies of off-grid solar products in a developing country, such as India. The literature on CBM revealed that transforming an organisation into a circular one requires to rethink value proposition, value creation and delivery as well as to redesign the way value is being captured. Repair, refurbishment and remanufacturing business models have already been analysed from a BM perspective but could be further developed given the limited number of publications. As the literature does not offer country-specific or sector-specific case studies of CBMI in the off-grid solar industry, the author argues that there is scope to understand what drives and hinders an organisation in such an ecosystem to consider repair, refurbishment, and remanufacturing strategies and business models. This research aims to address this knowledge gap. The off-grid solar sector plays a significant role in ensuring energy access and mitigate climate impacts. However, unless opportunities of inner loop strategies are identified by actors in the off-grid solar value chain or unless there are CE driven policy changes in the industry, the off-grid solar sector is likely to remain linear. Identifying which inner loop strategies are most likely to succeed in the Indian context along with strategic recommendations to enhance such strategies uptake are therefore needed.

Building the conceptual framework

Based on the literature review performed above, a conceptual framework representing the key factors and processes for circular business model innovation in the field of off-grid solar products was designed. The conceptual framework (see Figure 2 below) includes product-specific, internal and external factors influencing the choice of repair, refurbishment and remanufacturing strategies along with their operationalisation into a business model and the business model innovation process.

Product Specific Factors – *Definition: factors which influence the creation or integration of repair, refurbishment or remanufacturing strategies into the business model of an off-grid solar organisation; and are directly linked to the product itself (design, components, materials, volumes of used-products, spare parts and spare standardisation).* Off-grid solar products are made of several components with highly distinct product lifetimes, directly influencing repair, refurbishment and remanufacturing strategies. The design of the original product, its costs, the availability of spare parts and their standardisation as well as the used product quality and volumes, highly impact one organisation's ability to repair, refurbish and/or remanufacture products.

Internal Factors – *Definition: factors which influence the creation or integration of repair, refurbishment or remanufacturing strategies into the business model of an off-grid solar organisation; and are directly and easily influenced by the focal solar company that provides circular off-grid solar products. A focal off-grid solar company is either an OEM which distribute its products or an OES of circular SHS and SL.* An organisation's ability to repair, refurbish and remanufacture products depends on the structure of its supply chain as products need to be brought back to an OEM, an OES or a third party. Specific knowledge, skills and technology are necessary to ensure remanufacturing and repair activities. Business strategy, business organisation and operations are also influenced by remanufacturing strategies.

External Factors – *Definition: factors which influence the creation or integration of repair, refurbishment or remanufacturing strategies into the business model of an off-grid solar organisation; and are not directly and not easily influenced by the focal off-grid solar company.* Customer demand for repaired, refurbished or remanufactured products is one of the most important drivers for companies to consider product life extension strategies. Such demand is largely influenced by customers' perceptions. In the case of refurbishment and remanufacturing, policies at national and regional level also seem to hinder or drive an organisation's willingness to refurbish or remanufacture products.

Operationalisation in BM - The recent CBM literature identified that circular strategies are likely to influence what is the value proposition of a business and how the organisation creates, deliver and captures value. Hence, the choice of repair, refurbishment and/or remanufacturing strategies will directly influence the BM components of one focal off-grid solar company. Despite the existence of one framework for circular business models (Lewandowski, 2016), this thesis uses the BM canvas by Osterwalder et al. (2010) and the taxonomy by Richardson (2008) which are widely accepted in the literature. Indeed, the added take back and adopting factor components of Lewandowski (2016) can be integrated within the value creation and delivery components of the Osterwalder et al. (2010) framework.

CBMI process – With changes at the macro and micro level in a firm's environment, new opportunities and threats can emerge for an organisation. Such environmental changes might trigger the organisation to innovate in the way it operationalises its business strategies. CBMI slightly differs from the classic BMI, as it the CE requires a holistic and dynamic process, including co-creation and collaboration. The conceptual framework depicts the continuous process of BMI through a circular arrow and the learning process of an organisation.

To conclude, Figure 2 indicates that there is a mutual influence between the product life-extension strategies and the respective factors. Product-related, internal and external factors directly influence and might limit the choice and ability of one focal organisation to integrate repair, refurbishment or remanufacturing strategies into its existing or new business model. However, a focal organisation can also purposely innovate its business model to prioritise repair, refurbishment and/or remanufacturing strategies. Such innovation will consequently shape the off-grid solar product (e.g. design changes), the current stage of knowledge and technology level of the organisation (e.g. skill training; R&D investments), its business operations and can also to a certain extent influence policy and customers. In addition, the use of a circular arrow in the conceptual framework aims to highlight that CBMI is an iterative process with forth and back learning between the different group of factors and choice of product life extension strategies. However, most of the literature offers case studies that have been investigated in a developed country context. Therefore, the findings might be affected by the specific socio-economic context of these geographies. In addition, the unclarity of terminology and definitions used in the literature for repair, reuse, repair, refurbishment and remanufacturing might also blur the conceptual framework. Besides, the research on CBM and CBMI remain at its early stages and therefore, further research is needed to increase the reliability and generalisability of the reviewed literature findings and frameworks.

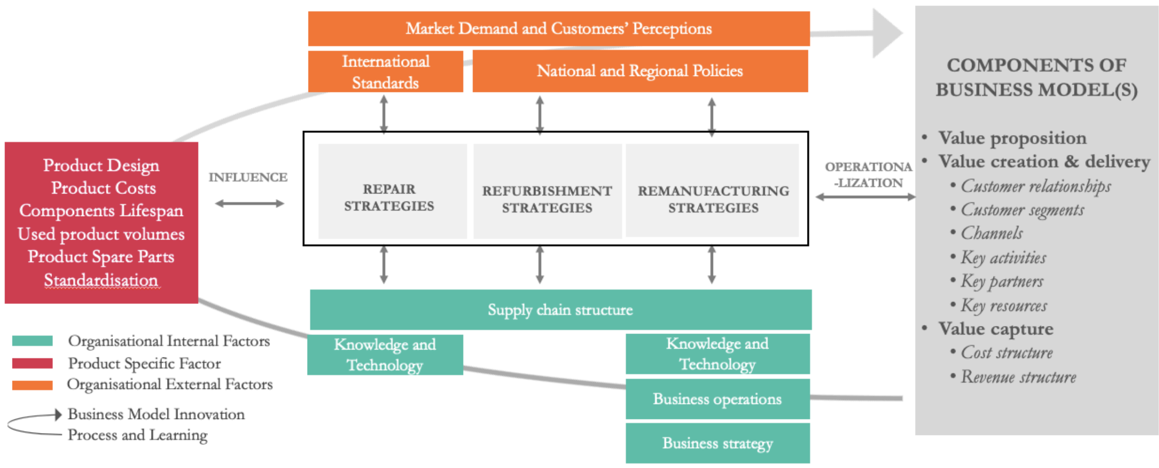

Figure 2: Conceptual Framework

Source: Own illustration

5 Findings and analysis

This section presents the findings of the research. Repair, refurbishment and remanufacturing strategies and BMs are individually studied in Section 5.1, 5.2 and 5.3. In each section, the results are organised by following the above conceptual framework which includes 1) factors influencing repair, refurbishment and remanufacturing BMI; 2) repair, refurbishment and remanufacturing strategies and 3) establishment of a potential new circular BM. The current challenges were categorised in three distinct dimensions based on the conceptual framework as defined in Section 4.3: product-specific factors, internal and external ones. In this chapter, the *focal organisation* is referred to as one OEM or one OES of solar home systems and/or solar lanterns implementing one or several product life extension strategies.

5.1 Repair and maintenance business models

5.1.1 Repair & maintenance BMs challenges

The below paragraph details the challenges mentioned by interviewees to explore and/or establish business models for repair and maintenance of SHS and SL.

Product Specific Factors

Repair and maintenance business models are challenging to establish because of product-specific factors including 1) poor design of SHS and SL; 2) non-standardisation and poor quality of SL; and 3) the lack of spare part availability and their standardisation.

Poor product design - First of all, the poor design of the studied off-grid solar products has been frequently brought up by several stakeholder groups including OEMs, foundations, social enterprises and incubators. The current product designs of SHS and SL do not facilitate repair, modularity and disassembly. The quote of Ananth Aravamudan, senior advisor in renewable energy solutions at the social enterprise incubator Villgro, illustrates a common and generic criticism made to off-grid solar products.

"These products are not built in a modular way, so it's not like if you can slide out a printed circuit board and slide it into another one. There's a lot of screwing and unscrewing. Modular design would have really helped but hasn't happened".

Down to the component level, even though not many interviewees precise design challenges in link with specific SHS and SL components, the design of the solar panel itself is identified as a challenge. Mounting solar cells in series impedes one's ability to repair down at the solar cell level. In addition, even though not mentioned by interviewees themselves, solar cells are protected by a specifically designed polymer layer, usually called, EVA film. Such films are used as shock absorbers and solar cells protectors in case of extreme weather, temperature and humidity (Svarc, 2018). This process of lamination of PV cells limits the repair of solar cells. Indeed, the most difficult process for solar PV recycling is to remove the encapsulant of laminated structures (Komoto & Lee, 2018).

Non-standardisation and poor quality of SL - Secondly, interviewees mentioned the lack of standardisation and poor quality of SL, making SL repairs more complex than for SHS. Many interviewees referred to low-quality solar lanterns manufactured in China. As an example, one senior manager (interviewee n°6) at a multinational fast-moving electric goods company noted that batteries usually cannot be removed out of solar lanterns, as the product cannot be easily opened. In his perspectives, changes of design should principally concern a simpler replacement of batteries, given that these are the components with the highest rate of failures. In most cases, the inability to open off-grid solar products with standardised repair tools also hinders one's ability to repair them.

Spare parts availability and standardisation - Moreover, to be able to perform efficient repair and maintenance services, the founder and managing director of Batti Ghar Foundation along with Mr. Sagar Mahapatra, managing director of Urjaa Samadhan highlighted the role of spare parts availability and their standardisation.

To conclude, amongst all product-specific factors identified, the design of products and the availability of spare parts are the biggest challenges mentioned by interviewees.

Internal Factors

The interviewed stakeholders have also underlined various factors internal to a focal organisation that pose a challenge to establish R&M business models. These include 1) the complexity to establish reverse logistics; 2) the lack of influence of distributors on OEMs; 3) the integration of R&M in the organisation's business strategy; and 4) limited financial resources of small enterprises.

Difficulty for OESs/OEMS to establish reverse logistics - Amongst internal factors mentioned by interviewees, the establishment of supply chains and reverse logistics is seen as the most critical roadblock for servicing SHS and SL. This is mostly due to the scattered and remote nature of households in need of off-grid solar products. Sagar Mahapatra from Urjaa Samadhan underlined that when repair services centres exist, most of them are located in urban areas, making it extremely difficult to be reached by rural households. In addition, the current lack of retail presence in rural areas is said to challenge the establishment of reverse logistics. Indeed, interviewees n°3 and n°4 from a global development institution referred to the difficulties of most off-grid solar brands to simply distribute their products to rural areas. Given the complexity of establishing reverse logistics in rural areas, most interviewees identified logistics as a significant cost driver for repair and maintenance BMs. Indeed, most interviewees perceived repair and maintenance as services performed by trained technicians in repair centres or by local technicians who need to commute to users' households. However, only one interviewee believed that users could be empowered to perform most of the repairs themselves if spare parts were made available. Such common belief amongst interviewees is not surprising given that off-grid solar products are not designed for repair and that there are, in most cases, no spare parts available.

Distributors' lack of influence on OEMs- Increasing the repairability of SHS and SL through design changes is said to be complex as India is only an off-grid solar product assembler and not a manufacturer. Interviewees in the distribution of off-grid solar products such as social enterprises and foundations refer to the weak influence that they have on OEMs to change product design. Rachna Arora from GIZ further addressed this issue by highlighting the fact that electronic companies' product designers and R&D teams are usually not based in India and therefore do not take into account the Indian ecosystem dynamics in which the product will evolve. Lastly, when discussing design challenges for repair of off-grid solar products, interviewees did not spontaneously identify the growing manufacturing base of solar panels in India as an opportunity to integrate design practices for repairability and disassembly in the off-grid solar market.

No integration of repairability within the current business strategy - From a business strategy perspective, one senior manager at a fast-moving electronic goods company underlined that off-grid solar products constituted only a small portion of their product portfolio, which currently limits the company to further invest in extending product life strategies. In addition, the fact that such BM is not traditionally integrated in the organisation is said to hinder the organisation's CBMI. In the case of small social enterprises and start-ups, the business strategy focuses on establishing sales networks and limited attention is usually given to establishing reverse logistics and repair services. Limited human resources make it challenging to consider establishing repair and maintenance services and the appropriate supply chains for it.

Lack of financial resources for small organisations- Having access to sufficient financial resources is considered as a challenge depending on the size of the organisations trying to offer repair services. Indeed, hindering factors for small organisations included a lack of financing for establishing reverse logistics, along with a lack of collaboration through partnerships. Consequently, some stakeholders highlight the need to subsidise the creation of such business models. However, the lack of financial resources was not mentioned as a significant challenge to implement repair business models. Most stakeholders perceive the largest players in the field as the ones having the most leverage and resources to implement SHS and SL servicing. From a government scheme perspective, interviewees agree that integrating repair and services costs into the programs should be prioritised by government and that future budgets of governmental schemes should account for such costs.

Regarding knowledge and technology factors, most interviewees believe that India as a country would have sufficient human capacity to provide such repairs and maintenance services. Proper training for repair and maintenance technicians are said to be necessary even though, there is no need of high-tech solutions for repair, according to Rachna Arora from GIZ. However, once again the non-standardisation of SHS and SL would make it difficult for technicians to know how to repair all product models on the market.

To conclude, establishing repair and maintenance business models for SHS and SL is first a logistical challenge due to the scattered nature of such products and then a business strategy issue for most off-grid solar OESs. However, both human and financial resources were not identified as hindering factors in the Indian context, which means that OEMs and OESs could prioritise such strategies if they had the willingness to.

External Factors

Numerous stakeholders also highlighted factors which are independent or difficult to influence by a focal organisation. For R&M business models, the most challenging external factors included the lack of market demand and low willingness to pay for such services. Policy aspects for repair and maintenance were not explicitly mentioned. However, several interviewees called for a common CE framework integrating the entire solar PV industry or even for a common mechanism to enable companies from all sectors to transition to the circular economy.

Low market demand & low willingness to pay for repair services after warranty - First of all, market demand for repair and customer's perceptions were frequently brought to light by interviewees, even though there was no consensus on whether servicing markets are a significant business opportunity for off-grid solar products. Under government schemes programs for SL and SHS distribution, interviewees noted that beneficiaries do not demand repair services. In the case of product failures, users store their products at home and hope to be given another SL in the future through government programs or through companies' CSR schemes. If they demand further repair and maintenance services, beneficiaries' willingness to pay for repair and maintenance services after warranty is said to be low or almost inexistent. Possible reasons can be that users are unaware of how long the repair and maintenance services will enable the product to last. As a consequence, the current volumes of off-grid solar products to be repaired were not seen as a strong business opportunity for local technicians as they did not foresee that such product repairs will significantly add to their existing revenues. In addition, due to the customer price sensitivity on the Indian market, some OEMs or OESs doubt the possibility to integrate further repair and maintenance services into the original product costs. The original level of the price of off-grid solar lanterns is said to influence the willingness of customers to pay for repair services versus getting a product replacement product. Given the price range difference between SHS and SL, it is likely that customers will be more likely to pay for repair of their SHS after the end of the warranty period than to get a product replacement.

Customer's ability to repair SHS- Secondly, most interviewees indicated that a trained technician should perform the repairs on SHS. Sagar Mahapatra from Urjaa Samadhan is the only interviewee that argued that most repairs could be performed at the household level by users themselves. In his perspectives, repairs of SHS would mostly require cleaning the solar panel or removing obstacles. The system's battery water level might also need to be readjusted or the fuse might have to be replaced. From a luminary perspective, a simple replacement of the broken light would be sufficient in most cases.

Lack of repair advocacy- Lastly, a general lack of advocacy for repair has been more commonly identified amongst interviewees' perceptions in the current SHS and SL ecosystem. However, the lack of existence of policy at local level to ensure repair was not commonly mentioned as hindering R&M business models.

To conclude, the most significant challenges for a focal organisation to adopt repair and maintenance business models include the lack of design for repairability and disassembly, the lack of availability of spare parts and their non-standardisation, the complexity and costs of establishing reverse logistics, low market demand for repair and low customers' willingness to pay for repair services.

5.1.2 Examples of repair and maintenance BMs in India

Interviews with OEMs and OESs offered examples of repair and maintenance business models currently operating in India. Such examples are further detailed below.

Some interviewed OEMs or OESs shared common aspects within their business models. One example is the replacement of the defect unit under warranty as long as the unit has not been physically damaged. One senior manager in a multinational fast-moving electric goods organisation (i.e. interviewee n°6) specified that, in the case of a default of the product, which includes battery failure under warranty, the product is taken back from the customer through outsourced logistics. The replacement of the product includes the costs of logistics from the distributor/retailer to the company's warehouse, the labour costs and the product replacement costs. Costs associated with the replacement of units under warranty are already built-in in product prices. However, as of today, warranty schemes do not include repair and maintenance services for the units sold by that organisation.

However, the case of India also offers successful examples of repair BMs. Most interviewed organisations in the manufacturing and distribution of SHS and SL offer repair and maintenance services when the product is under a warranty scheme, but the operationalisation of such services varies greatly from one company to another. It is important to note that the below examples originate from interviewed social enterprises, non-for-profit organisations or incubators.

As an example, a managing director of an off-grid solar solution provider (i.e. interviewee n°7) explained the organisation's reliance on local empowered entrepreneurs to sell off-grid solar products and ensure after-sales services. In practice, when a consumer needs R&M services, the user has to drop a complaint to either the original retailer or the after-sales teams. If the product is still considered to be under warranty, the product is then collected by the after-sales team who is present locally and sent back to the original equipment manufacturer for replacement. If repair is possible (i.e. depending on the agreement with manufacturers and the type of product), it is provided by local technicians. Such model is similar to the one developed by Urjaa Samadhan where one local person is responsible for selling SHS locally and for being the point of contact for after-sales services, in a parameter of about 200 villages. In the case of repair, the customer can directly contact the local technician who is well known in the village and has been technically trained. In cases where repair and maintenance operations cannot be performed, the product will be collected and send through logistics from the rural areas to Urjaa Samadhan's office.

On the contrary, one operation manager from a SHS and SL Original Equipment manufacturer (i.e. interviewee n°5) presented a more centralised approach to product servicing. During the last three to five years, the organisation has developed seven services centres around the country. Operated by the organisation itself, the services centre welcome defect products under warranty and outside of warranty in exchange for a service fee, covering the full cost of repair. In this approach, customers are bearing the cost of transportation and time to such services centres, located in urban areas.

Another example in the field is the BM developed by SELCO Solar Light Private Ltd which has developed 60 energy service centres located in small to mid-sized towns around the country. Within each centre, there are technically trained employees who handle approximately 2000 to 2500 service calls daily through a toll-free number. The customer service branch employs more than 20% of the workforce of SELCO Solar Light Private Ltd. SELCO's customers are usually given one year of free servicing and then can buy additional repair and maintenance services through an annual maintenance contract. To ensure the appropriate training of local employees, the organisation has established partnerships with local institutes and technical colleges. To conclude, the organisation has been prioritising sales and services since its creation and as an integrating part of its business strategy. Therefore, it ensures a high availability of spare parts for product repairs.

5.1.3 Business model innovation factors for repair

Factors pushing organisations to innovate their business models for repair and maintenance services were identified in numerous conversations with interviewees and are presented in the below section. They include both micro and macro factors, as defined per the literature review on business model innovation.

Identification of a strong business opportunity for repair and maintenance services - As mentioned in Section 5.1.1, no consensus on whether R&M services are a significant business opportunity has been reached so far. However, for Sagar Mahapatra, managing director of Urjaa Samadhan, the repair market is a significant opportunity, which however has not yet been recognised by most stakeholders. Palak Aggarwal added that this will be seen as an opportunity once stakeholders in the ecosystem were able to turn R&M services in a bankable business model. For interviewee n°6, R&M services are seen as a strong business opportunity if they generate new revenue streams. As an example, interviewee n°6 argued that a BM could be established to enable batteries replacement in both SHS and SL, which could increase the organisation's revenues steams and its competitive advantage on the Indian market.

Integrating more stringent tendering requirements for government schemes – According to numerous interviewees, government schemes for off-grid solar product distribution have not fully integrated and monitored repair and maintenance services. Making tendering requirements more stringent by increasing the time of warranty and developing processes for R&M services monitoring would send a strong message to the market and force OEMs and OESs to innovate. Such requirements could also come from financial institutions offering product financing to off-grid solar customers.

Creating a supportive environment – According to interviewees, creating a supportive environment would require advocating for repair and maintenance services and developing a supportive environment for new start-ups to emerge. To advocate for R&M, Mandvi Singh at CSE recommended quantifying the financial loss of off-grid solar products that remain used in rural households because they require R&M services. Such quantified data would push the Indian government to create more stringent tendering requirements and monitoring processes. In addition to bringing general awareness on the issue, there is also a need to support new start-ups entering the off-grid solar market to plan and implement R&M services. This informational support is currently provided by both Villgro and SELCO Foundation when incubating start-ups.

A committed management - Lastly, the social and environmental commitment of the founders of Batti Ghar Foundation and SELCO Solar Light Pvt Ltd drove the organisations to integrate R&M services. As an example, Palak Aggarwal, founder of Batti Ghar Foundation, noted that the organisation is not blind to solar solutions. Therefore, the organisation does not wish to address one Sustainable Development Goal (e.g. SDG 7 Affordable and clean energy) by going against another one (i.e. generating additional waste).

To conclude, the most commonly identified BMI factors by participants include the perception of a strong business opportunity and the creation of more stringent repair and maintenance requirements for tendering processes. This can mostly be explained by the significant volumes of SHS and SL tendered under governmental schemes.

5.1.4 Ideation of potential business strategies for repair

Throughout the interviews, stakeholders came up with several ideas for current or new organisations to explore R&M strategies. The below section presents the strategies for repair and maintenance identified by interviewees but also ideas generated by the author herself. Each of these strategies description details 1) how the business strategy addresses one or several challenges identified in Section 5.1.1; 2) the potential benefits of such strategy; 3) its potential disadvantages and 4) the current state of the proposed strategy in different contexts. Table 8 synthetises the challenges addressed by the proposed business strategies.

(1) Design for disassembly to replace batteries in SHS and SL

Description: By changing the design of SL and SHS, users would be able to open their off-grid solar products and replace the lithium-ion battery. When the product is not under a warranty scheme, the lithium-ion battery would be bought as a spare part as it would be widely distributed in the country.

Interviewees mentioned at several occasions the lack of design for repairability and disassembly of SHS and SL. In addition, the battery remains the weakest component from a lifetime perspective in SHS and SL. Therefore, one way to extend SHS and SL product life is to replace the battery when it comes at its end-of-life by designing products that can be easily opened and equipped with a standardised and easy to exchange battery. If this process is made simple and safe for users, rural households themselves could be operating their battery replacements, which would likely reduce the cost of repairs outside of warranty. The willingness to pay for the battery is likely to be high for SHS given that a battery replacement will be cheaper than replacing the full system. However, this assumption does not hold for solar lanterns as SL are cheap appliances with a short lifetime. One of the benefits of this strategy is the generation of new revenues streams for the organisation, which will make it easier for the organisation to explore such BMI. However, this strategy heavily relies on the ability of OESs to supply standardised lithium-ion batteries at the last mile. One drawback of this strategy is that it requires significant changes of design which has been said to be difficult to conduct by OESs. Therefore, this BMI is more likely to emerge from the largest off-grid solar products OESs operating on the Indian market or from the current Indian OEMs aiming to establish a competitive advantage over low-quality Chinese products. In addition, at the design level, one potential drawback is the question of whether the product will remain durable if it is made easy to open. The project *Solar What?!* presented in Chapter 3 has proven that this duality does not necessarily hold and that the replacement of a battery by users in a solar torch is technically possible. However, its viability from a commercial perspective still has to be established in the Indian context. Moreover, based on the conversation that the author had with Rowan Spear, OEMs might perceive this strategy as a strategic risk as technical information on the product would have to be made aware to the users, and therefore to competitors.

(2) Offer annual maintenance contracts to SHS and SL customers after the warranty

Description: Once the customers' original warranty has expired, the customer has the opportunity to buy an annual maintenance contract for SHS and SL to extend its warranty at a reasonable cost.

In the private player-driven market, the warranty period for SHS and SL usually lasts one to two years. Once the warranty expires, if the product fails, some organisations may offer repair and maintenance for a service fee. Users' willingness to pay for such repair services are perceived to be low because of the unknown quality of the repair and unknown remaining time of use of their products. If a focal organisation were to offer an additional annual warranty, the rural household's confidence in the quality of the repair would likely increase. If many customers show interest in such annual maintenance contracts, it might also force the focal OEMs or OESs to manufacture or select products of higher quality and durability to limit as much as possible the costs of repairs. However, such a strategy seems only possible in the case of the private player-driven market, but not for the under governmental schemes market segment where rural households are given products for free. In addition, it is also more likely to be successful for highly priced products such as SHS, as the replacement of a product is likely to be more expensive than paying for annual maintenance contracts. In the case of solar lanterns, the customers' willingness to pay for such additional services will likely depend on the price difference between the maintenance contract annual costs and the replacement product. Urjaa Samadhan is currently experimenting such contracts.

(3) Integration of a monitoring system in SHS to remotely track the performance of the system and alert SHS users of the encountered problem and its potential solutions

Description: The SHS includes an Internet-of-Thing technology to remotely monitor the system. The OES can easily identify how the system performs and which issues the system is currently experiencing. Under a warranty scheme, through a simple phone call, the user is made aware of the problem and is guided to solve it himself/herself.

One of the biggest challenges identified by interviewees is the logistic complexity of offering repair services at the last mile given the scattered localisation of such products in India. Instead of sending a technician to every village or empowering local technicians who are unlikely to make a livelihood from of off-grid solar product repairs, this strategy empowers users to be responsible for most of their SHS repair and maintenance. From a customer perspective, the benefits of integrating such technology into SHS is that the product is continuously maintained to deliver its full performance, thereby maximising the output of the SHS and prolonging its lifetime. With minimum efforts, customers will be made aware of their systems' issues through a phone call and will be able to fix them. If users are not able to perform such repairs, then the OESs will know the localisation of the product, the issue encountered by the system and the tools and spare parts needed to perform the repair, thereby limiting the cost of repairs to its bare minimum. This might also increase the trust of customers into repair and maintenance services. From a business perspective, this process is likely to be less human resource intensive as only a minimal number of local technicians would have to be employed. Challenges linked to this strategy include the financial viability of the GSM (Global System for Mobile Communication) system once the customer has fully paid the product under the Pay-as-you-go system. Indeed, running such technology has a cost for a focal organisation and who will bear that cost once the ownership is fully transferred to the customer is a question that remains. However, one potential solution, according to Felix Boldt from Solar Worx, is to limit the amount of data collected by the system sent to the OES. Instead of collecting data hourly, the system could collect data less frequently, reducing the cost of operations. In addition, maintaining this technology system running can be an opportunity to sell spare parts to the customer in the future, thereby generating additional revenue streams. Such a system is currently being run as a pilot by Urjaa Samadhan in India and also run by Solar Worx in sub-Saharan Africa. It is also widely used in solar water pumps system as highlighted by a recent GOGLA article (Gogla, 2019b).

Based on the described challenges, the author also identified additional business strategies which could enhance repair and maintenance services of SHS and SL in the country.

(4) Create a joint coalition between OEMs and OESs for repair services of SHS

Description: The largest solar home systems manufacturers and suppliers on the Indian market could build a coalition for repair services, under and after warranty.

Established servicing markets for off-grid solar products, as described in 5.1.3, are presently individual initiatives from off-grid solar brands. However, it is currently difficult for one single organisation to ensure repair services in the whole country, given the scattered localisation of products in the country and the organisations' cost and revenue structure. Given these two facts, there would be scope for SHS brands to join forces and establish a pan India repair market for SHS, under and after warranty. Such a strategy would primarily target SHS, as interviewees mentioned that current solar lanterns are too customised and non-standardised to be able to be repaired. Benefits of such a coalition would include economies-of-scale and also extended geographic coverage depending on each brands' presence in the country. Potential economies-of-scale might reduce the price of repairs, which 1) is likely to decrease the repair costs for the organisation to cover warranty claims and 2) is likely to increase the customers' willingness to pay for repairs after warranty. This strategy will also address the challenge of insufficient volumes to be repaired. Indeed, local technicians will not only be able to repair one type of SHS brand but several ones. In addition, such trained technicians could also be resellers of lithium-ion batteries and collectors of used ones. Repairs performed by the coalition will likely increase trust in repairs as well as demand for such services. Moreover, the company's lack of willingness to engage with repair and maintenance services will be tackled. Indeed, if the industry joins forces, it is very likely that no company would like to stay behind, putting at risk its brand image and potentially its competitive advantage. However, interviewees have mentioned the lack of collaboration in the industry and the fear of market data leakages, which in practice, significantly hinders the potential development of such coalition. In addition, given the current state of product design, it will probably be challenging to perform such repairs unless products are designed for repair and disassembly in the first place. Lastly, given the variety of SHS and SL in the market and their lack of spare parts availability and standardisation, it will probably be complex for a local technician to know how to repair them all and to have the required spare parts. To the authors' best knowledge, no current example of such a coalition in the worldwide off-grid sector exists. Therefore, its viability remains to be demonstrated.

5.1.5 Proposing a new R&M business model

Based on the identified R&M strategies, this study offers one potential business model combining the above four strategies. This business model proposition is following the business model components of value proposition, value creation and delivery and value capture from the conceptual framework. However, it needs further validation and testing in the Indian context.

Value proposition – Providing rural households and businesses with off-grid lighting services at lower life-cycle costs, with higher reliability, shorter downtimes, and a high level of user convenience is the value proposition of this newly proposed R&M business model. Challenges identified by interviewees showed that some customers lack information on what to do and whom to contact when their product requires repair and maintenance, in particular since some repair centres provided by brands are located in far-away areas. Therefore, there is a need to build a value proposition based on convenience and ease of repair and maintenance services. Based on the strategies presented, convenience aspects of repair will originate from the remote monitoring system as the SHS users would easily be made aware of the issue encountered by their system and will be guided by phone to ensure the repair and maintenance themselves. Convenience will also arise from being able to buy lithium-ion batteries for battery replacement at the last mile. Outside of the two-year warranty scheme, convenience of repair will occur thanks to the annual contract maintenance. Therefore, the low-cost aspect of the value proposition will be a critical aspect of the value proposition, given the price sensitivity of SHS and SL customers. Further studies to establish such costs is vital for such BM to be economically viable in the Indian context.

While interviewees themselves did not spontaneously mention any environmental or social value proposition of repair and maintenance services, one could argue that extending product life of lighting solutions would generate the positive social impacts identified in Section 3.3. In addition, extending product life preserves the value, complexity, as well as the embedded energy and labour of a product (Bocken, Bakker, et al., 2016; Ellen MacArthur Foundation, 2015; Geissdoerfer, Savaget, Bocken, et al., 2017). Life Cycle Analysis (LCA) studies will be needed to determine whether repair services will be beneficial from an environmental perspective (Kalmykova et al.,2018).

Key activities – The above-proposed strategies would most likely include activities of 1) design, 2) technology development, 3) supply chains and logistics, 4) repair and maintenance, and 5) customer services. First of all, design changes should make it easy for SHS and SL users to open their products and replace their used battery without compromising the performance and durability of the product. Design activities might also occur for the integration of the remote monitoring system into SHS, which might require specific R&D. Key activities might also include technology development if the existing technology used in the CloudSolar project by Urjaa Samadhan, or any alternative technology, is not being widely commercialised. Thirdly, developing and running appropriate supply chains for standardised lithium-ion batteries would be required. Establishing and adopting standards for lithium-ion batteries should not be complex, given the existence of the IEC battery standard certifications. Indeed, the IEC 60086 is an international standard ensuring the battery interchangeability in products. Lithium batteries are standardised in terms of dimensions, nomenclature, terminal configuration, marking among also safety, performance and test methods (TÜV SÜD, n.d.). In addition, repairs and maintenances activities will be either directly performed by the brand-specific or coalition-specific technicians under warranty or under the annual maintenance contracts. Lastly, customer services activities would be required in all cases, but especially with the integration of the remote monitoring system, where OESs would be bearing the cost of contacting SHS users.

Key customer segments – Customer segments are likely to differ from one strategy to another. Indeed, for annual contract maintenance and SHS remote monitoring systems, customer segments would probably target users who wish to extend their product life and have an easy solution for repair and maintenance. Customers targets for annual maintenance contracts would also include regular users of SHS and SL due to the Indian market price sensitivity. According to interviewee n°6, lithium-ion battery replacement would be performed both for the brand specific products and non-brand specific products. Therefore, based on the interviewee's perspectives, customer segments could include both the brand's traditional customer segments as well as any other off-grid solar customer in need of a lithium-ion battery replacement.

Key customer relationships – Many interviewees referred to the lack of trust of customers into off-grid solar solutions because of the weak industry's servicing market. To restore this trust and further built it, off-grid solar products brands need to establish close customer relationships. One way to maintain close customer relationships would be to frequently communicate with SHS users on the state of their products' performance, the need for replacement of the battery or the need to buy a new annual maintenance contract. In addition, a first user training to familiarise the user with the system would be required. The coalition of repair would lead local technicians to be well known in the village and trusted, therefore building closer customer relationships with off-grid solar products users.

Key channels – For repair and maintenance services performed by the brands' coalition, and for battery replacement, key channels will use local trained technicians as distribution channels of such services and products. Indeed, the only examples of successful BM for repair and maintenance in India rely on locally train technicians or empowered entrepreneurs (e.g. Dharma Life and SELCO Solar Light Pvt Ltd.) operating at the last mile. Alternative distribution channels could also include classic retailers of off-grid solar products and spare parts. Indeed, interviewee n°6 identified the opportunity to leverage the brand presence and its distribution system in the country for lithium-ion replacement batteries.

Key resources and capabilities – Resources needed for operationalising such strategies are mostly human resources to execute repairs and maintenances services on the product but also ensure a close customer service relationship by phone through the remote monitoring system. Capabilities will include technical skills for repairs, but also communication skills to support the user into repairing/maintenance his/her off-grid solar product.

Key stakeholders/partnerships – To be able to implement such R&M business strategies, the key partnerships for focal organisations are 1) the local technicians and 2) off-grid solar competitors. Indeed, customer services employees and local technicians are the most important stakeholders to ensure that R&M services are performed on the phone and ground. In the specific case of the OESs coalition, all off-grid solar competitors become essential partners to ensure the viability of the coalition. Lastly, one could easily ague that customers are key stakeholders as their satisfaction and their willingness to pay for such services would directly influence the financial viability of the BM.

Value capture - To ensure the financial viability of such a business model, the revenue streams need to balance the costs. Revenues generations and costs structures are detailed for each of the four strategies presented.

Interviewee n°6 explained how a cost and revenue structure could look like for lithium-ion battery replacement. For this model to be financially viable, the revenues generated from lithium-ion batteries sales need to be high. It requires a large base of lithium-ion batteries customers in the country as well as a high customer willingness to pay. Given that the cost of lithium-ion batteries is expected to decrease with technology development and its market development in the coming years, customers' willingness to pay for battery replacement is likely to increase. In addition, imitating the system developed for lead-acid batteries in India would ensure further revenue generations. Indeed, if the customer is incentivised to return his/her used battery to the OESs or OEMs, the focal organisation is then able to sell the used battery for refurbishment or recycling. However, according to findings in Chapter 3 and interviewees, no current refurbishment or recycling facility of lithium-ion batteries has been developed in the country.

For annual maintenance contract, revenue generation originates from the sale of contracts. As an example, Urjaa Samadhan charges less than one monthly payment under the Pay-as-you-go system for an annual maintenance contract. The most significant costs generated are likely to be to the cost of spare parts, the cost of service provided by the local trained technician as well as logistics costs. For annual maintenance contracts to be financially viable, only a certain number of products can fail and therefore, this is why Urjaa Samadhan decided to supply only high-quality SHS.

Lastly, the cost of the remote monitoring system includes the cost of the technology and the cost of servicing the technology. Such costs should be built-in in the monthly payment of the pay-as-you-go system. Additional revenue generation can originate from the ability to sell spare parts when the system requires.

Table 9: Challenges addressed by new R&M business strategies

	BMs Challenges	***Strategy n°1:*** *Replace Lithium-ion batteries*	***Strategy n°2:*** *Offer annual maintenance contracts*	***Strategy n°3:*** *Implement monitoring technology in SHS*	***Strategy n°4:*** *Build a coalition for repair*
PRODUCT SPECIFIC	Difficult Product disassembly	New design required			
PRODUCT SPECIFIC	Poor quality of SL		Need to increase quality for durability		
PRODUCT SPECIFIC	Spare part unavailability	Lithium-ion battery need to be made available in the whole country			
PRODUCT SPECIFIC	Lack of spare part standardisation	Lithium-ion batteries are standardised			
NTERNAL	Supply chain structures	Lithium-batteries are widely distributed		No need for logistics	Economies of scale
NTERNAL	India is "only" an assembler and not a manufacturer				

	Off-grid products are only a small % of the total business product portfolio				Effort shared by the industry
	Lack of large companies' willingness	Motivation to repair because of new revenues generation		Potentially less costly as it is remote monitoring	Pressure from the industry & fear of competitive advantage loss
	Limited human resources to focus on servicing (in start-ups)			Potentially less human resource intensive	Potentially less human resource intensive as shared initiative
EXTERNAL	Customer demand for R&M		High demand as cost of repairs outside of warranty or cost of replacement might be higher		Cheaper repairs so increase in demand
	Customer willingness to pay for R&M	Cheaper to buy a replacement battery than a full new SHS	Increase customers' trust in the repairs	Increase customers' trust in the repairs	Increase customers' trust in the repairs and repairs are cheaper

Source: Own illustration

The matrix provided in Table 8 highlights the complementarity of the proposed circular strategies. Indeed, while strategy n°1 and 2 mostly address product-specific and external factors, strategy n°3 and 4 only tackles internal and external factors. However, such strategies cannot alter the fact that India is foremost a product assembler rather than a product manufacturer.

5.2 Refurbishment Business Models

5.2.1 Refurbishment BMs challenges

The below sections detail the challenges mentioned by interviewees to explore business models for refurbishment of SHS and SL. It is noteworthy that in most cases, interviewees did not mention which components could be refurbished or not, thereby keeping the conversation around refurbishment of SHS and SL fairly generic.

Product Specific Factors

Exploring refurbishment business models for SHS and SL leads to product-specific challenges including 1) perceived poor performance and quality of refurbished products; 2) lack of sufficient volumes for refurbishment; and 3) safety concerns about lithium-ion batteries' refurbishment.

Reduced performance and quality of refurbished products - The challenge most commonly expressed by interviewees is the poor performance and quality of refurbished products. With previous use of the SHS or SL, both their efficiency as well as their general quality might have been reduced. Such reduced performance directly influences customers' demand and their willingness to pay for refurbished products, as further detailed in the external factor category below. To reassure customers about the quality and performance of refurbished SHS and SL, most interviewees recommend the use of a warranty scheme. As an example of interviewees' perceptions on warranty, Ananth Aravamudan, senior advisor at Villgro specified that:

"Unless there is a way to actually certify those refurbished components and to warranty them to something. It may not be the original 10 or 15 years but at least 2 or 3 years, that would give me confidence. That facility today doesn't exist, but I know that similar concepts are coming from the mobile phone market or used car market where I can actually go and buy a mobile phone which is refurbished or a reused one."

Need for standardised high volumes - However, refurbishment of SHS and SL components would require large volumes to become a financially viable solution. According to interviewee n°1, refurbishment of solar PV in the European context remains unclear because of the lack of solar PV volumes reaching their end-of-use. Indeed, because of the long lifetime of solar PV, larges volumes have not yet arisen to make a refurbishment facility economically viable. In the solar PV context, another significant challenge is the non-standardisation of solar PV that could be collected and be refurbished. The need for standardised and high volumes for refurbishment has also been confirmed for the Indian context. Taking lithium-ion batteries as an example, Prodip Chatterjee, the Founder of Nunam (i.e. a start-up aiming to refurbish computer lithium batteries into battery energy storages units) stressed the need for high volumes as the organisation's business relies on low margins.

Safety concerns about lithium-ion batteries - Certain challenges linked to the safety of refurbished batteries still arose. Indeed, in the case of lithium-batterie refurbishment, Prodip Chatterjee, the only interviewee with expertise on lithium-ion battery refurbishment, underlined the following:

"People have concerns [about lithium-ion refurbished batteries], but it's not like they are against. For example, generally our partner organisation likes what we do but, they are sceptic on the safety topic: can someone be hurt? And these are also our concerns".

To conclude, the lower quality of refurbished SHS and SL and the need for high volumes are the most critical hindering factors for the development of refurbishment BMs in the Indian context. Quite interestingly, interviewees did not refer to specific design challenges of SHS or SL for refurbishment. However, because such design challenges have been made so clear for repair strategies, it is reasonable to assume that product design is also a critical issue for any refurbishment strategy.

Internal Factors

Exploring refurbishment business models for SHS and SL leads to company specific challenges including 1) supply refurbished products or components at the right quantity, quality and price; 2) unestablished technical feasibility; 3) complex integration of refurbishing strategy into current BM and brand strategy; and 4) large investments required.

Ensuring the supply of refurbished products/components – Having access to used components has been said to be the most significant challenge for a refurbishing business model for lithium-ion batteries. Supply is a challenge both with regard to volume, quality and price aspects. As a unique example, Prodip Chatterjee declared:

"Our number one priority is supply. If we don't have supply on these batteries, then there's nothing".

Similarly, the challenge of supply for refurbishment/recycling was mentioned by Palak Aggarwal from the Batti Ghar Foundation. During a pilot for collection of defect solar solutions in Odisha, the Batti Ghar Foundation understood that rural households in the Odisha State were not ready to give away their solar products for free. Indeed, they perceive a higher residual monetary value in their used off-grid solar products. In this context, rural households were demanding the replacement of their lighting solutions at home in exchange for their defect units. Such element was also identified by interviewee n°7 from Dharma Life as he highlighted the need to incentivise customers to return defect off-grid solar products. Lastly, most interviewees agreed upon the logistical challenge for refurbishing products due, once again, to the scattered nature of products and the non-existence of established reverse logistics.

Unproven technical feasibility - In addition, the feasibility of refurbishment of solar panels remains unknown so far, as explained by the managing director of a PV recycling facility in Europe (i.e. interviewee n°1). Indeed, the integration of second-hand panels into an existing PV system, as well as the use of second-hand batteries as energy storage unit, remain to be demonstrated. Even though this statement applies to large-scale PV, it is reasonable to expect that such technical feasibility is also to be demonstrated in the off-grid solar sector. This remaining question mark on the technical feasibility of refurbishment has been confirmed by a fellow (i.e. interviewee n°10) at an Indian Environment Research Institute for solar panels and lithium-ion batteries. In her perspective, the output and efficiency of the refurbished product would be extremely limited. However, with smart applied engineering, the organisation Nunam is trying to refurbish/repurpose laptop batteries for a low-load battery energy storage. For the case of lithium-ion batteries, the technical feasibility of refurbishment depends on what type of used lithium batteries are refurbished, the quality of those batteries and the load for which they will be reused. Interviewee n°10 also perceived refurbishment to be complex because of the assembly role of India in the off-grid solar value chain. Such statement underlines that for interviewee n°10, refurbishment requires technical modifications directly from OEMS.

Integration of refurbished products into the business strategy and brand positioning - From a business strategy perspective, the fear of coexistence of refurbished and new SHS and SL on the market was not mentioned by interviewees except by a representative of company X5. The interviewee underlined the business risk of having these two products on the market, as a refurbished product would necessarily be cheaper and therefore could cannibalise sales of new products. In addition, the brand positioning could suffer from such strategic choice according to interviewee n°6, senior manager from a multinational fast-moving electric goods. This is probably due to the perceived lower quality of refurbished products.

Large investments required - The investments required to establish proper refurbishing infrastructures were only mentioned by interviewee n°10. In her views, the refurbishment of solar panels would require specific laboratories as existing traditional infrastructures of refurbishment in the country are in the informal sector and said to be of poor quality. The costs associated with refurbishment processes are said to be high in the European context according to the managing director of a solar PV recycling facility in Europe (i.e. interview n°1). Costs in the Indian context might be lower through, due to the country's lower labour cost.

To conclude, accessing the right amounts, quality and correctly priced refurbished products/components and ensuring their refurbishment from a technical perspective are the largest internal hindering factors for SHS and SL refurbishment.

External Factors

Factors independent of a focal organisation or difficult to influence include 1) the lack of policy and standards for refurbishment; 2) negative customers' perceptions of refurbished products; and 3) the lack of a proper ecosystem for refurbishment.

Lack of policy and standards for refurbished products - The lack of policy for refurbishment has been highlighted by interviewees for solar PV and lithium-ion batteries. In the European context, the inexistence of regulations, frameworks, standards and common definitions of what is a reused solar panel hinder the development of solar PV refurbishment. Indeed, the definition of a refurbished solar PV remains unclear, making it easy for many actors in the sector to qualify a solar PV as a refurbished one. Given the general lack of policy around solar waste in India as mentioned by the representative of an association (i.e. interviewee n°2), it is reasonable to assume that such policy and standards are missing in the India context as well. Indian stakeholders also identified this lack of policy is also identified in the case of lithium-ion batteries. Refurbished lithium-ion batteries cannot be easily supplied today because of a lack of regulations for their commercialisation. Consequently, refurbishment businesses necessarily operate in a grey area, and for most cases in the informal sector.

Negative customers' perceptions of refurbished products– Most interviewees assumed that customers of off-grid solar products hold negative perceptions about refurbished SHS and SL. Indeed, customers usually buy off-grid solar products as emergency lighting solutions. Therefore, interviewee n° 6 assumed that most of them would not want to take the risk to buy a used product and see it fail in the future. Besides, rural households' customers are said to prefer new products as the product novelty aspect is a source of pride in the village. Consequently, these negative perceptions will influence their willingness to pay for refurbished products. Such willingness to pay will likely depend on the price difference of a new versus a secondary SHS/ SL. If the price difference is perceived as being relatively small (which will depend on customer segments), then there is a chance that the customer will not take the risk of buying a second-hand product. According to interviewee n°1, this small price difference originates both from the cost reduction of solar PV and its fast technology advancement. The second-hand panels on the market are likely to include only a few types of panels. To illustrate such challenge, interviewee n°1 specified that:

"Ten years ago, one could buy a new panel with a maximum watt peak output of 180 or 200 watts for the panel. At the same time the purchase cost for the buyer was at 800 euros for one piece. Today, you can purchase the same panel with now a watt peak output of 400 Wp and a purchase price of 80 euros. It dropped down with a tremendous number. So, the panels became cheap, let's say, relatively cheap. The second-hand panels were sold two years ago at 60 euros for a panel. If the new panels are still going down in the next years to come, I wonder economically how viable it will be to be active in this second-hand market of PV panels. I am not saying it is no longer impossible, but it will be very selective by picking out which panels are economically fit and acceptable for reuse as second hand. For example, when a panel has a hot spot and one want to repair this it and sell this again, it might be that all the costs put together plus the margin might come very close to the price of a new panel. When the new panel is at that time the double of watt peak output and contains the latest technology, compared with a second-hand panel of for example 6 years old and older technology, it is the market which shall decide what they choose."

Lack of ecosystem for refurbishment – Several interviewees pointed out the lack of infrastructure and an established ecosystem for refurbishment but did not further detail such barriers during the interviews.

To conclude, the most hindering factors to implement refurbishments business models for SHS and SL in India are to supply used products at the right quality, price and volumes, to be able to technically refurbish SHS and SL components and to create a demand for this new category of products. Without any policy or standards that set quality requirements for refurbishment processes and products, it is doubtful that a formal refurbished market will emerge in the country.

5.2.2 Example of refurbishments BMs in India

The interviewees offered only a few examples of refurbishment business models that currently operate in the off-grid solar market in India. Such examples are presented below.

Currently, only one example of a viable business model for refurbishing of SHS or SL exists on the Indian market. Looking at product refurbishment (and not component refurbishment as a spare part), only one interviewed OES (i.e. company X5) refurbishes SHS and SL for product replacements. Their refurbishment process involves that the customer returns its defect unit to the original warehouse, which will then send it to one of the two refurbishment centres available in the country. On the small product line of each refurbishment centre, employees dismantle defect products and check every original product component. The components that comply with the organisation's refurbishment guidelines will be reassembled and repaired, and subsequently offered as replacement products to customers under warranty schemes.

Another well-established example is the refurbishment of lead-acid batteries. Several interviewees mentioned the existence of an established market for refurbished lead acid batteries with established supply chains. Beyond the fact that customers get a discount on new batteries when they return their used ones, details on how such business models function for lead-acid batteries were not provided by interviewees. However, the refurbishment process in itself was described as technically accessible by several interviewees.

Lastly, Nunam is an example of repurposing/refurbishing laptop lithium-ion batteries into energy storage systems, which can be used as back-up storages. The value proposition for customers is to provide a reliable and performant energy storage device at a reduced cost. Even though complementary customer analysis is required, the refurbished aspect does not appear to be the most critical selling point for refurbished lithium-ion batteries. Indeed, Prodip Chatterjee, the Founder of such organisation highlighted:

"I think it is very simple. What do you need is a great product, at a good price which somebody wants to have. It is very simple. [...] Consider that you don't care, or that you are not educated enough, or you don't care if it is used or new, it is good or bad for the environment. Most people don't care. So, if you want to succeed, you build X, Y, Z product with let's say reused (components) at a good price and then if people like it, they will buy it. And this is how you're having a business model. [...] There's no difference between selling an Iphone where nothing is reused against selling our product where maybe some elements are reused. Ultimately the customer logic is the same. I have X, Y, Z money in my wallet which I want to spend, and then I am buying where I have most value and something that I like. I think this is how it works."

The types of activities being performed to refurbish laptop lithium-ion batteries into an energy storage unit are complex and numerous. The simplified process includes to: 1) collect used batteries from e-waste dealers; 2) dismantle them; 3) run several tests on the cells; 4) use a matching algorithm to group the cells into one pack; and 5) create a functional unit by integrating the right battery management system and design. To establish such a business model, the organisation relies on key partnerships with e-waste dealers from both the informal and formal sectors to supply used laptop batteries. It also requires several resources and capabilities such as: 1) smart people with applied engineering and applied sciences knowledge; and 2) significant investment as such BM implies large working capital for storage and testing infrastructures. Even though Nunam does not yet distribute its products on the market, the organisation is likely to face two options for its distribution channels. Either the organisation can partner with an existing distributor such as SELCO Solar Light Pvt Ltd. using a B2B to B2C model, or the organisation builds its distribution channels. However, to ensure such distribution to be cost-effective and flexible in rural areas, Prodip Chatterjee highlighted the need to innovate from current distribution channels and further engage with customers. Lastly, to ensure its financial viability, the model relies on high-volumes and low margins of sales but also on almost-free used assets. Prodip Chatterjee mentioned the use of standard reverse calculation for ensuring the financial viability of the product on the market. He details the process of standard reverse calculation as follow:

"This is also then quite straightforward. What we do or what we have done so far is we look at the price point of lead-acid batteries and they are really well-known in the market. So, you take the product which is successful in most of these areas today and the price points are known. So, you take the price point and cut at 15% of that price or 20% and then you will reverse calculate and see, can you, at that price, make the product with that performance and get capacity, yes or no? If the answer is no, then you have a good product but you're not able to sell it, or it is not going to be helpful because you're having something more expensive. If the answer is yes, then you might have a good chance. [...] This is our standard reverse calculation."

5.2.3 BMI factors for refurbishment

Factors influencing organisations to consider refurbishment business model for SHS and SL are numerous and fragmented. They involve 1) introduction of policies and standards; 2) identification of strong customer demand; 3) identification of successful refurbishment BMs and 4) strengthening the value proposition.

Introduction of policy and standards for refurbished products - For interviewee n°1 and Prodip Chatterjee from Nunam, the introduction of clear regulations, frameworks and definitions for reused solar product/ lithium-ion batteries is necessary for any organisation moving forward into refurbishment BMs. In addition, research institutes and advocacy bodies in India have mentioned that the private market players should be the driving force of refurbishment activities. As an example, Rachna Arora, Deputy Team Leader & Coordinator for the European Union Resource Efficiency Initiative in India at GIZ highlighted:

"I see a little bit the role of the private sector to be stronger. As I said, in the automobile sector, it is not the government. From the government you can ask a level playing field, you can ask to set up the policy and standard processes to check the quality and other parameters, but I think it is the industry which should be pushing because it is in their interest to save more and more resources by getting the product refurbished. How much can the government influence other than creating hubs for people to get training around it, or by providing that opportunity for people to get skilled under it? I think it should be private sector-driven".

Identification of customer demand - To encourage business model innovation for refurbishment, interviewees mentioned the need to identify a customer demand for it, which largely depends on customers' level of awareness on the existence and performance of refurbished SHS and SL. A lack of current customer demand for refurbished product significantly hinders its further development.

Identification of successful refurbishment BMs - OEMs and OESs referred to the need to see other actors in the off-grid sector being successful with their refurbishment business model before they can embrace BMI themselves. Finally, OESs are open to pilot refurbished off-grid solar solutions on their market, but this would require off-grid solar manufacturers to be the ones pushing and driving such innovation.

Strengthen the value proposition of off-grid solar products - For Nunam, the original motivation was to break down the cost of solar solutions for rural areas by providing cheaper energy storages units.

To conclude, the most significant drivers of business model innovation for refurbishment is the introduction of clear policy frameworks and standards for refurbishment processes as well as the identification of customer demand for second-hand SHS.

5.2.4 Ideation for potential business strategies for refurbishment

Despite some interviewees' enthusiasm about the potential of refurbishment, ideation for refurbishment BMs was more challenging for them than for repair and maintenance business models. However, two potential strategies were identified, based on interviewees' responses and the author ideation. Each of these strategies description details 1) how the business strategy addresses one or several challenges identified in Section 5.2.1; 2) the potential benefits of such strategy; 3) its potential disadvantages and 4) the current state of the approach in different contexts. Table 9 synthetises the above-described challenges addressed by the proposed business strategies.

It is important to note that the below-presented strategies only target SHS, as SL were said to be of very low quality, difficult to open, disassemble and repair. Consequently, the ability to extend the life of solar lanterns through refurbishment seems highly compromised in the current Indian context. The implementation of strategies of design for disassembly and repair of SL could trigger further considerations for refurbishing solar lanterns.

(1) Offer refurbished SHS for giveaway projects

Description: OEMs and OESs could offer refurbished products as giveaway to underprivileged communities that cannot afford them.

As highlighted in Section 5.2.2, scaling refurbishment strategies leads to numerous challenges due to the difficulty of supplying used products, at the right price, quality and volume and due to lack of customer demand for such products. Therefore, making it a fully scalable business strategy seemed to be logistically and financially complex for any focal organisation. However, without turning refurbishment into a scalable business strategy, a focal organisation could already identify an opportunity to refurbish SHS in small volumes and give it away to rural communities that cannot afford to finance them. Defect SHS that cannot be repaired by local technicians could be collected under a warranty scheme through the company's local technicians, as proposed in several of the repair strategies outlined in Section 5.1.4. Therefore, offering refurbishing SHS as donations to underprivileged communities relying on the local technicians for collection would ensure the complementary of the product life extension strategies proposed in this research.

In such a context, the reduced energy output and performance of refurbished SHS is unlikely to hinder the viability of such BM. Indeed, poor rural communities would rather have one workable lighting solution than no solution at all, according to Ananth Aravamudan. Using such a strategy, the focal organisation will only refurbish SHS when defect units are collected and repaired for secondary use. Therefore, to be financially viable, such a strategy does not require to collect high volumes of products. As the refurbished SHS will not be commercialised, there will be no risk of sales cannibalisation and brand image damages. Indeed, the refurbished product will fully operate on a separate market targeting different customer segments. Benefits of such solutions would include the provision of free products to customer segments that still lack an energy solution, enabling them to move up the energy ladder. It will also familiarise them with off-grid solar products and the associated brand, which could trigger additional off-grid solar sales for the company once such customer groups will be able to finance solar systems themselves. However, numerous drawbacks still arise as no standards for refurbishment exist. First, it seems that there is a legal risk for an organisation to do this in the current Indian context.

Moreover, there is a risk that the organisation would provide refurbished products not sufficiently tested for safety and quality. If receiving communities experience severe safety issues with one of the company's refurbished products, this could likely influence the customers' perceptions of the brand for future purchasing, and potentially the customers' trust in off-grid solar products. To make sure that such issues do not arise, the focal organisation should develop minimum internal standards for safety and quality checks. Lastly, the drawback of such a solution could be that the focal organisations stopped exploring and testing ideas to further commercialise refurbished product given their current efforts in giveaway projects. Given that no current example of refurbished off-grid solar products has been identified, the logistical and financial feasibility of this strategy still needs to be demonstrated in the Indian context. However, the informal conversation held with Rowan Spear highlighted that refurbishment is currently being discussed and considered for the *Solar What?!* project.

(2) Conduct a pilot to refurbish SHS by OEMs and OESs with the largest volumes on the Indian market

Description: OEMs and OESs s with the largest volumes of SHS on the market could conduct a pilot to collect defect SHS units.

As the financial viability of refurbishment business models lies in high volumes of standardised used products, OEMs and OESs with the largest volumes placed on the Indian market should be the drivers of refurbishment strategies. Either individually or through a coalition of the largest actors, brands with the highest SHS volumes could conduct a pilot for collection and refurbishment of defect SHS units. In the case where customers or local technicians cannot perform repairs themselves under a warranty or extended warranty scheme, SHS could be collected and then refurbished by alternative channels. Several reverse logistics channels could be tested in this pilot such as: 1) local technicians' networks; 2) existing government distribution channels; 3) micro finance institutions networks; and 4) aggregators of mixed brands. The use of local technicians as collector of defect units seems well-aligned with strategies depicted in Section 5.1.4. Indeed, the local trained technician could attempt to repair the product, and otherwise, technicians could collect the defect unit and send it back to the OEM, the OES or to a third-party refurbisher. For Palak Aggarwal from the Batti Ghar Foundation, local entrepreneurs who are part of a government training program could also collect the defect products, store it, refurbish it and resell it for a source of income. In the perspective of interviewee n°3 and n°4, program managers at global development institution, incentivising microfinance institutions or developing a network of aggregators for several brands could also be potential collection channels of defect units. More precisely, Palak Aggarwal specified that aggregators could also be local stores acting as defect units-collectors. However, interviewees did not identify potential synergies with e-waste collection services, an opportunity that could be further researched and tested.

In addition, the viability of such a refurbishment strategy highly depends on incentive schemes for rural households. One potential solution brought up by Palak Aggarwal would be to use the system of governmental distribution of basic goods. As an example, the focal organisation could make sure to compensate rural households for their defect off-grid solar products by offering them additional basic goods, such as rice and sugar, which are already being distributed in village centres. Alternatively, a focal organisation could implement a price reduction on a new unit of the same brand or coalition of brands. Such refurbishment pilot could highly beneficiate the focal organisation. First of all, it would provide relevant answers to the following questions: which types of SHS should be collected? With which quality? Which components can or cannot be reused? How to certify the quality of the refurbished products? How large of an investment should be made to scale-up the process? The pilot would also enable the focal organisation(s) to test the financial viability on the market, in a context of fast technology change and costs reductions of SHS. Potentially, collection of defected SHS can generate additional revenues either through refurbished SHS sales or through selling components to scrap dealers or refurbishers. The generation of additional revenues through refurbished SHS sales highly depends on what types of customers segments are targeted. Indeed, to ensure that second-hand SHS do not cannibalise products sales, refurbished SHS would have to target new customer segments. Using a pilot as an experiment could highlight whether attracting new customers segments would increase the brand presence and recognition in the country and if it could fit the current brand image strategy. In addition, for defect components from used SHS, additional revenues can be generated by selling used components such as batteries, cables to e-waste dealers and used solar PV to solar PV recyclers. In some cases, the focal organisation might not be able to fully refurbish all SHS components but could supply industrial scale refurbishers. No existing model of a successful refurbishment business model in the off-grid solar sector has been identified yet. Therefore, the ability to conduct such a pilot in the Indian context remains to be demonstrated.

Table 10: Challenges addressed by new refurbishment business strategies

	BMs Challenges	***Strategy n°1:*** *Offer refurbished products for give-away projects*	***Strategy n°2:*** *Conduct pilot for refurbishing SHS*
PRODUCT SPECIFIC	Poorer performance and quality of refurbished products	Does not matter given the customer segment	To be tested through pilot
	Need of standardised and high volumes used products/components	No need for industrial capacity	High volumes as piloted by larger organisations with higher volumes on market
	Safety concerns for lithium-ion batteries		
INTERNAL	Ensuring supply of refurbished products/components	No need for large volumes as it is project-based	Capitalise on existing infrastructures, brand presence and incentives for product return
	Unproven technical feasibility	To be tested	To be tested through pilot
	Integration of refurbished products into the business strategy and brand positioning	Not at risk in giveaway projects	Enables testing of integration into current strategy through pilot
	Large required investments	Not necessary in give-away project	To be tested through pilot
EXTERAL	Lack of policy and standards		
	Negative customers' perceptions of refurbished products	Does not hold in this case	To be tested through pilot
	Lack of ecosystem for refurbishment		

Source: Own illustration

Despite the complementary benefits of strategies n°1 and n°2, key barriers still prevail such as the lack of policy and standards, safety concerns about batteries refurbishment and a lack of a proper ecosystem for refurbishment. Given that strategy n°1 would only provide relatively few units of refurbished products, it could be argued that this would not lead the focal organisation to truly innovate its business model(s) and drastically modify the way it creates and delivers value. Similar criticisms apply to strategy n°2, which entails the use of a pilot to experiment the logistical, technical and financial feasibility of refurbishing SHS in India. In addition, too many questions remain unanswered for establishing refurbishment BMs of SHS. Consequently, no complete refurbishment BM has been proposed to the degree as for repair and maintenance business models (Section 5.1.5).

5.3 Remanufacturing Business Models

In comparison with repair and refurbishment business models, remanufacturing business strategies and the associated challenges were barely discussed during the interviews. Interviewees did not refer to any existing remanufacturing organisation of SHS and SL, specifying that there currently is no discussion on remanufacturing in India. In addition, no ideas on how such business models could operate were clearly outlined by interviewees. Despite this, some interviewees highlighted some challenges to remanufacturing.

Product Specific Factors

Product-specific factors included 1) the technical feasibility of remanufacturing solar panels; and 2) the lack of sufficient volumes of solar panels.

Technical feasibility - Interviewees shared their doubts on the technical feasibility of solar panel remanufacturing, given that solar panel cells are mounted in series and given that the energy efficiency of a remanufactured panel will be lower than of a new one. The purity of the material such as silicon will be altered, affecting the quality of the product. However, remanufacturing of charge regulators and luminaries would need further exploration. No mentioning of remanufacturing of batteries was made by the interviewees.

Lack of volumes - As in refurbishment, remanufacturing off-grid solar products seems complex given the current limited volumes of defect products. This assumption mostly accounts for SHS. The reason given by interviewees is the long lifetime of the solar panel. Consequently, the business opportunity seems compromised but may be promising in the future when waste volumes increase

Internal Factors

Supply chains of defect products - India is not a manufacturer of off-grid solar products, but an assembler of product components usually produced in China. Therefore, ensuring remanufacturing of SHS and SL would require products to be returned to the original manufacturers. In addition, the large investments required for establishing remanufacturing processes seems to hinder its development.

External Factors

Customer demand – As in refurbishing, interviewees mention that whether there will be customer demand for remanufactured SHS and SL still needs to be proven.

6 Discussion

The objective of this research has been to investigate how circular business models could be designed to extend the product life of solar home systems and solar lanterns in India. With regard to this objective, this chapter presents and discusses the major findings and their implications and answers the three research questions, as stated in Chapter 1.

RQ1: Which circular business strategies to extend product life of solar home systems and solar lanterns could potentially emerge in the context of India?

RQ2: What types of value proposition, value creation, value delivery and value capture for circular business model seem possible in such context?

RQ3: What are the drivers and barriers to the implementation of such product life extension strategies and business models?

The findings are then placed in the current literature and practical debate of circular strategies in the off-grid solar sector, highlighting the research's contribution to the state of knowledge. A discussion on the importance of such findings both in practice (i.e. for private and public actors in the off-grid solar sector), as well as in academia is proposed. To nuance these findings, the research's methodological and practical limitations are presented. Lastly, axes for further research to advance the field of CBM and CBMI in the off-grid solar industry are outlined.

6.1 Overview of the findings and their significance

(RQ1) Which circular business strategies to extend product life of solar home systems and solar lanterns could potentially emerge in the context of India?

In the Indian context, the exploration and testing of circular business strategies for SHS and SL would most easily and immediately prioritise repair and maintenance, over refurbishment and remanufacturing. Proposed repair and maintenance business strategies to advance product life extension are to integrate a remote monitoring system in SHS, to provide annual maintenance contract and to enable lithium-ion battery replacement for SHS and SL. A key catalyst of this repair transition would be the creation of an off-grid solar industry coalition for repair.

The potential refurbishment business strategies to advance product life extension in India are to offer refurbished SHS for give-away projects and, for the largest players in the Indian market to conduct a pilot for collection and refurbishment of defect SHS. Remanufacturing is not seen as an opportunity in the current Indian context. Lastly, most strategies refer to batteries and solar panels, while LEDs and charge controllers are left out of the discussions in most cases.

(RQ2) What types of value proposition, value creation, value delivery and value capture for circular business model seem possible in such context?

The research proposes the integration of the four identified repair and maintenance strategies into one business model. The value proposition of this model focuses on offering reliable electricity services at lower life cycle costs, with shorter downtimes and high convenience of repair and maintenance services. This value proposition would be of interest to solar home systems and solar lantern end customers in need of a long-lasting energy solution and customers of non-off-grid solar product in need of a standardised lithium-ion batteries replacement. It would require strong customer relationships which can be strengthened via customer care services and customer training. This business model relies on strongly developed channels of customers services through local trained technicians and entrepreneurs, off-grid solar product retailers and/or logistic service providers. Key resources include trained technicians with strong technical skills and customer service employees with strong communication skills. Activities will include 1) product design for repairability, 2) technology development for integrating the latest IoT technology for remote controlling into SHS, 3) the supply chains and logistics, 4) repair and maintenance services and 5) customer care services. In terms of value capture, business model revenue streams include lithium-ion replacement batteries sales, used lithium batteries sales to recyclers, annual maintenance contracts and monthly payment through the Pay-as-you go system. This financial structure would be viable as long as revenues streams outweigh the product and services costs and enable the company to reach its required margins.

(RQ3) What are the drivers and barriers to the implementation of such product life extension strategies and business models?

The most common challenges for repair business models include the lack of product design for repairability, the lack of spare part availability and their non-standardisation, the complexity and costs of establishing reverse logistics along with low market demand and limited willingness-to-pay for repair services. Drivers of BMI for repair include a strong market demand for repair services and strengthening tendering requirements of governmental schemes.

In the case of refurbishment, challenges include the supply of used products at the right quality, price and volumes, the technical feasibility of SHS and SL refurbishment along with the lack of customer demand and appropriate refurbishment policy and standards. Drivers of BMI for refurbishment include clear policy frameworks and standards for refurbishment activities and the identification of market demand for second hand SHS.

The significance and implications of these findings, as well as their contribution to the existing literature and practical debate are further discussed in the below sections.

6.1.1 Potential circular strategies and BMs for repair and maintenance

(RQ1) - The four strategies for repair and maintenance as well as the newly proposed business model show that there is a scope for OEMs and OESs to sell both an energy product along with repair and maintenance services. These services are deemed necessary for using off-grid solar products in the long run and maintain customers' trust (Lighting Global, 2016). These findings are of high importance for the sustainable growth of the off-grid solar industry in India but also for those of other countries and regions in the world facing a similar lack of repair and maintenance services for solar-powered solutions. The findings confirm the ones established by Cross & Murray (2018) in Kenya. The two authors argued that the off-grid solar industry should commit to sustainable design and distribution of spare parts and components at the last-mile if Africa's energy transition is to be sustainable, both socially and environmentally. In addition, the predominance of repair and maintenance services in this thesis aligns with the findings presented in the earlier literature (see Chapter 4). One potential explanation for this could be the lower amount of investment required for R&M strategies than for other inner-loop strategies. According to the report on Circular Economy opportunities in India by the Ellen MacArthur Foundation (2016b), investment initiatives with short-term pay-back times should be prioritised given the high costs of transitions inhibiting the scaling up of the circular economy in the country. In this thesis, repair and maintenance strategies as well the newly proposed repair business model seemed to intuitively require limited investments from the focal organisation's perspective, in particular in comparison with refurbishment and remanufacturing, which would require large infrastructure investments. In addition, this thesis argues that prioritising repair and maintenance services is a matter of ensuring energy justice. Indeed, as mentioned by Cross & Murray (2018), energy justice is not only about distributing appliances to have access to energy but is about taking into account repair, access to material and spare parts, design and knowledge.

Such a perspective on energy justice is also underlined by Nathan (2014) who wonders whether it is fair to push solar PV systems in rural areas that lack supply chains and human skills to maintain them.

While strategies of the remote monitoring system and battery replacement were identified in the literature review, this thesis brings two new contributions to the repair literature, specifically proposing an advanced annual maintenance contract scheme and the formation of an OEMs/OESs repair coalition. The absence of such a coalition in the literature is not surprising given the required complexity of collaboration between industry actors that operate in a very competitive market. However, it reflects well earlier observations that circular business model innovation requires co-creation and collaboration with stakeholders (Bocken et al., 2019; Pieroni et al., 2019).

(RQ2) - From a business model perspective, this thesis's findings also contribute to the existing body of literature on the building blocks of repair business model. Indeed, the literature emphasised the environmental value of repair and maintenance but did not investigate a clear value proposition that is directed to the customer. Based on the findings of this research, the author argues that service reliability, service convenience and low cost of services are crucial dimensions of a value proposition for off-grid solar product repair in the Indian context. From a customer segment perspective, customers opting for repair and maintenance services are cost-conscious customers, an observation that is well-aligned with the findings of Lüdeke-Freund et al. (2019) and Bocken et al. (2016). Also well aligned with Lüdeke-Freund et al. (2019), most stakeholders and key partners required are OEMs and service providers, including local trained technicians and entrepreneurs. However, given the need for customers to actively engage in repair and maintenance services with the implementation of a remote monitoring system, customers are also key stakeholders for repair identified by this research. Consequently, close customer relationships are necessary to provide the necessary training and assistance. In addition, the set of activities for repair and services is far more complex in the case of off-grid solar products than what was generically described by Lüdeke-Freund et al. (2019). Indeed, on top of providing the necessary repair and maintenance services through logistics and customer care service, activities of product design and technology development are first required to make SHS and SL repairable. From a channel perspective, this research has shown that local channels through trained technicians or existing retailers are necessary, highlighting the importance of last-mile tailored channels. Lastly, this research contributed to the general body of knowledge on repair and maintenance BMs in the off-grid solar sector by identifying new source of revenue generation including spare parts sales and sales of defect components for recycling through take-back.

(RQ3) – This research noticed the main factors influencing repair and maintenance strategies identified in Chapter 4 but also made new contributions to the literature. Indeed, this research confirmed the literature review findings on the significant role played by design strategies for repair as well as design strategies for standardisation and compatibility. It highlights the findings of Bocken et al. (2016), which stressed the need for design strategies to work hand in hand with circular business models. In addition, spare part availability, reverse logistics and market demand were also identified as factors influencing the establishment of repair BMs. However, this thesis also underlined the crucial role that technology can play through the integration of a remote monitoring system into SHS. In addition, the reviewed literature did not identify the existence of national and regional policy as a crucial factor for repair. In the Indian context, because public procurement is such a significant market for OEMs and OESs, national policy and more precisely tendering requirements become an important external factor. Moreover, this thesis contributes to the literature of repair BMs as a successful repair BM largely depends on the degree of integration of repair strategies into the focal organisation business strategy and purpose.

6.1.2 Potential circular strategies for refurbishment

(RQ1) - The fact that only two refurbishment strategies were identified and that no new business model for refurbishment could be established reveals how complex refurbishment strategies for SHS are in the Indian context. Unless refurbishment technical feasibility is being proven, and that major policy barriers are being removed, refurbishment business models for SHS are unlikely to arise in India's near future. Such unlikeliness of SHS refurbishment is in line with the findings of Strupeit & Bocken (2019) on solar PV. Therefore, such finding expands the existing body of literature in the circular economy field for the off-grid solar industry. In addition, this thesis highlights that refurbished give-aways SHS as well as a pilot for refurbishment can be two strategies for the sector to initiate reflections in the refurbishment sector. Indeed, as mentioned by Vermunt et al. (2019), experiments can address technology and knowledge barriers. In addition, such an experimental pilot could also accelerate the sustainable transition of the off-grid solar industry (Bocken, Weissbrod, & Tennant, 2016; Bocken et al., 2018). Answering the numerous questions raised for refurbishment through a pilot are crucial not only for SHS but also for other solar-powered products and industrial sectors which manufacture or distribute batteries, solar panels, LEDs and charge controllers.

(RQ3) – As identified in the literature, the supply of used products at the right quality, price and volumes, along with the lack of customer demand and appropriate refurbishment policy and standards are significant challenges for refurbishment BMs. However, this research highlights that the technical feasibility of refurbishment of SHS and SL also influences a focal organisation's choice of a circular strategy.

6.2 Recommendations for policymakers and off-grid solar actors

Based on the perspectives and empirical data presented in this thesis, the following sections present complementary policy and business strategy recommendations to catalyse SHS and SL circular transition towards R&M and refurbishment.

6.2.1 Policy recommendations

First of all, the research findings reveal that both repair and refurbishment business model innovation could be triggered if policy standards and frameworks were either being introduced or strengthened. While the proposed strategies presented in Chapter 5 would tackle numerous identified challenges, they cannot alone adequately address the shift towards repair and refurbishment BMs (see Table 8 and 9). Therefore, there is scope for the Indian government and associated ministries to support and accelerate the adoption of circular strategies through adequate policies. In addition, the provision of off-grid solar products to rural households generates numerous social and environmental benefits (see Chapter 2). Consequently, the creation of dedicated policies for product life extension business models might be justified by the additional value that product life extension strategies entail.

Based on the collected data, three policy recommendations were identified to support repair, refurbishment and remanufacturing BMs:

(1) Strengthen tendering requirements to further include repair and maintenance services and monitor their implementation as well as strengthen MNRE specifications

Several interviewees highlighted the role of policymakers in advancing repair and maintenance strategies. To illustrate such statement, Mandvi Singh, program manager of the Renewable Energy team at CSE highlighted the need and opportunity to develop a repair market especially in the case of government schemes: *"There is definitively scope for the repair market to come up. [...] This means that a product which is 100% subsided, or close to 100% subsided by government is just sitting un-used because the service market is not there. There's enough scope, in fact urgently required."* In addition, Ananth Aravamudan, senior advisor at Villgro (i.e. a social enterprise incubator) introduced the idea of increasing the warranty time under the Ministry of New and Renewable Energy product specifications. Indeed, such increase of the warranty would send a signal to the market as some microfinance institutions only financially support customers when products are compliant with MNRE standards. In addition, for numerous interviewees, stringent requirements would include an extended warranty time but also a verified process for warranty enforcement.

This policy recommendation is crucial for the development of the off-grid solar sector in the country. Indeed, interviewees highlighted that the lack of a servicing market under government schemes has deeply affected the trust and faith that customers place in solar products. Because customers experience product failures, there is a growing belief that solar as an energy solution is not functioning. This could prevent current customers groups under government schemes from investing in solar-based solutions in the future. In addition, such findings are highly relevant for other solar products currently supported by government schemes, such as solar pumps. Indeed, through the KUSUM scheme introduced in March 2018, a significant uptake of the technology amongst farmers is expected as 1.75 millions of solar pumps will be distributed by 2022 (Gogla & cKinetics, 2019). The proper functioning and maintenance of solar pumps is essential to ensure the resiliency of Indian farmers facing the impact of climate change, farmers' economic development, as well as the Indian transition towards renewable energy (Gogla, 2019b; Suman, 2018).

To conclude, repair and maintenance strategies for SHS and SL and their integration into BMs can largely be influenced by government tendering processes under the assumption that the government-driven market is significant in volume and value. This conclusion is a new contribution to the body of literature on factors influencing repair and maintenance BMs and supports the finding of the Ellen MacArthur Foundation (2016b). Indeed, the Foundation's report on the CE in India precised that the country's transition to a circular economy will require the integration of circular economy principles into the currently undertaken government initiatives, and that public procurement could support the broader adoption of circular business models.

(2) Create a favourable environment for refurbishment by creating refurbishment standards and removing refurbishment policy barriers

The empirical data presented in this thesis shows that the establishment of refurbishment activities remains constrained by its current illegality for lithium-ion batteries and by a lack of standards for both lithium batteries and solar PV. First of all, the formalisation of refurbishment activities of SHS and SL components (among many others) would trigger the interest of the off-grid solar industry for refurbishment activities. Additionally, the creation of standards for refurbishment would establish minimum safety and quality guidelines for refurbished off-grid solar products and their customers. Given the previous role of the Lighting Global Program in ensuring minimum quality standards for SHS and SL consumers, standards could be further developed under the same program. Alternatively, this role might also be taken by individual OEMs, or by GOGLA, the largest off-grid solar association. These findings and recommendations expand the crucial role of national and regional policy not only for remanufacturing but also for refurbishment (Sharma et al., 2016; Wang et al., 2015).

This policy recommendation is essential as policy currently is the largest barrier for refurbishment of lithium-ion batteries and solar PV. Removing policy barriers would have consequences beyond the off-grid solar sector as both the market of electric vehicles (EV) and solar PV are experiencing fast growth in the country. Indeed, India's ambition is to reach more than 200 million electric two-wheelers, 34 million electric cars and 2.5 million electric buses by 2030 (Bhattacharjya et al., 2018). The European Union's Resource Efficiency Initiative in India has shown that there are opportunities to reuse EV batteries in solar projects and in energy storage applications, if processes and standards to verify and certify second life EV batteries exist. Therefore, removing existing policy barriers for the refurbishment of lithium-ion batteries would be beneficial both in the off-grid solar sector as well as in the EV sector. Similarly, through the National Solar Mission, India has set a target to achieve a 100 GW of solar electricity generation, leading to significant streams of end-of-life panels that could potentially be refurbished, if technically and financially viable. Indeed, sales of repaired panels as replacements or second-hand items were identified as circular strategies for greening the PV value chain (Arora et al., 2018). Once again, enabling the refurbishment of standardised second-hand solar panels would ensure a circular transition of both the off-grid as well as on-grid solar industry. Lastly, the introduction of such policies and standards would levy entry barriers for entrepreneurs in the field of refurbishment, which could directly contribute to growing the base of circular entrepreneurship in the country. This is of high importance given that the Ellen MacArthur Foundation identified innovative business models as a key driver of circular economy adoption in India (Ellen MacArthur Foundation, 2016b).

(3) Build incentives for Indian off-grid solar products and solar PV manufacturers to integrate upstream challenges

As identified by the Ellen MacArthur Foundation (2016b), the development of circular business models in India could build the country's competitive advantage and create an industry momentum. Therefore, Indian policymakers could incentivise Indian solar home systems and solar lanterns manufacturers to integrate designs for repairability and dissasembly. This design change could be an opportunity for India to build a competitive advantage against low-quality off-grid solar products that are currently mostly manufactured in China. In addition, such opportunity also arises for the solar PV industry. Indeed, as the solar PV manufacturing base is growing in the country, challenges of poor quality, repairability and disassembly could be integrated into upstream design decisions. Again, incentives for solar PV manufacturers to integrate these upstream challenges could be part of adequate policy programmes.

These recommendations are also relevant from a resource-efficiency perspective. Indian off-grid solar product manufacturers and the Indian solar PV industry could integrate remanufacturing strategies in their current BMs. Such strategies could be an opportunity to reduce material demand, ensure the preservation of existing material flows and would increase India's material resiliency. However, such a strategy has not been identified as a major resource efficiency opportunity by the GIZ report on greening the solar PV value chain (Arora et al., 2018).

To conclude, this research highlights the significant role of policymakers in enabling circular business models in the off-grid solar sector. Such policy recommendations are of high relevance to India but could also be relevant to other countries where 1) SHS and SL are sold in large volumes, 2) government-driven markets are significant, 3) customers are cost-conscious and 4) policy barriers remain. This will mostly be of relevance for sub-Saharan Africa which is the largest region in terms of units sold (i.e. more than 2.2 million units), followed by East Africa (i.e. more than 1,8 million units) (Francioso et al., 2018).

6.2.2 Implications for on-going projects in India and elsewhere

In the Indian context, the findings have direct implications for the development of the Solar Waste Project lead by the consultancy firm Sofies. Indeed, this project focuses mainly on evaluating the potential for the collection and recycling of off-grid solar products. Despite the need to establish as an end-of-life strategy for off-grid solar products, recycling does not incentivise OEMs to explore, test and adopt strategies to extend SHS and SL lifetimes. Indeed, as highlighted by Cross & Murray's (2018) (see Chapter 4) recycling strategies have been pushed as the ideal strategy in Kenya without taking into consideration existing economies of repair in the country. In India, actors in the off-grid solar ecosystem might prioritise low investment circular strategies and low-hanging fruits such as offering further repair and maintenance services. Indeed, the country lacks recycling infrastructure for such product streams and the investments associated with building such recycling facilities are high. Repair and maintenance strategies will impact the design of products and the standardisation of some components, thereby impacting the ease of recyclability of such products. Consequently, once a proper recycling solution has been identified, tested and implemented, it might create a lock-in for OEMs to change their product design, potentially inhibiting products' repairability and ease of disassembly. Such conclusions might also hold for other emerging economies developing a recycling solution.

6.3 Critical reflections and further research

6.3.1 Methodological reflections

Research questions

The limited and recent literature on circular strategies in the solar PV and particularly in the off-grid solar industry shows that CBMI in the sector is still a recent phenomenon. Consequently, the author has opted for a broad approach to the topic of product life extension strategies and the associated drivers and barriers for SHS and SL. This has led the author to explore the topics of repair, refurbishment and remanufacturing BMs but has limited her abilities to get in-depth inputs about specific business model building blocks. In addition, as more than 50% of the interviewees wanted to remain anonymous, the research questions seem to be sensitive. However, no critical information on the uniqueness of business models or companies' competitive advantages were shared with the author. Such sensitivity might have reduced the quantity and richness of information shared during the interview process. For example, questions linked to the government's public procurement process for SHS and SL and associated repair and maintenance services were sometimes not answered or answered in very general terms. However, the reasons for such attitudes remain unknown.

Limitations of using interviews in social research

The choice of interviews as the main source of primary data collection comes with limitations, affecting the reliability of the results. Interviewees' perceptions and inputs are filtered through their own views, and the presence of the author as well as her relationship with the consultancy group Sofies might have influenced interviewees' responses (Creswell, 2014). As an example, interviewees offered a variety of perspectives on the growth of the market of off-grid products. Going against the market data of the 2018 Gogla market report, some interviewees doubt the growth of the off-grid sector given the government's efforts in further extending the grid in India. This perspective could have significantly influenced their answers given the human and financial investments required for CBMI. In addition, Creswell (2014) noted that interviewees do not articulate their views equally. This might have compromised the author's ability to compare interviewees' views between one another.

Sampling

As a study's sample typically impacts the reliability and generalisability of the findings, the selected interviewees and the stakeholder group they represent should be kept in mind while analysing the findings of this thesis. Indeed, as described in Chapter 2, no policymakers, customers groups or microfinance institutions were interviewed. However, these stakeholders play a significant role in the off-grid value chain: the government as an important buyer through public procurement and through policymaking regulating the industry; customers through customer demand for SHS and SL; and microfinance institutions as necessary financial support for off-grid solar products purchasing. The inputs of the MNRE or other relevant ministries would have undoubtedly provided more diverse inputs on policy recommendations and their feasibility in the current political context. In addition, interviews with addition stakeholders would have provided valuable insights on customers' needs and wants and the role that microfinance institutions can play. It is important to note here that the author tried to contact government representatives through Sofies' direct contacts, but no attempts were made to reach customers groups and microfinance institutions, given time and language limitations.

Interview process

Limitations originating from the interview process included ideation challenges, the limited time for interviews, a poor understanding of refurbishment and remanufacturing terminology and linguistic and cultural differences.

The interview process required research participants to identify drivers, barriers and new potential business strategies for repair, refurbishment and remanufacturing of SHS and SL. This forward-looking approach and the novelty of the research topic made it difficult for interviewees to generate innovative business strategies and business model dimensions. This difficulty is not surprising given that CBMI generally requires a high level of ecosystem understanding, an analysis of sustainability costs and benefits as well as an evaluation of sustainability and circularity components (Antikainen & Valkokari, 2016). Setting up longer interviews or creating a joint workshop might have allowed for a stronger ideation process. However, given the limited available time of interviewees, such options were not deemed possible.

In the author's perspective, 30 to 75 minute-interviews are insufficient to explore the three topics of repair, refurbishment and remanufacturing BMs in-depth as well as drivers and barriers for CBMI. Given the limited interview time, the author was not able to research the complementarity of repair, refurbishment and remanufacturing strategies. Indeed, the interview questionnaire available in Appendix C highlights how repair, refurbishment and remanufacturing were presented to interviewees as three distinct topics rather than potentially complementary ones. In addition, as Chapter 4 highlighted the predominant role of repair and maintenance in the off-grid solar sector, the interview process started with exploring such topic. However, such interview choice offered less time to the interviewee to reflect on refurbishment and remanufacturing, which potentially affected the findings. Furthermore, such time limitations did not allow the author and interviewees to study in further details all components of SHS and SL.

During the interview process, the author also noted confusion about refurbishment and remanufacturing terminologies. As much as possible, the author tried to provide examples and explanations to illustrate their meanings. Confusions also originated in the degree of implication of the OEM in refurbishing and/or remanufacturing which remains unclear both in the literature and in practice.

Lastly, the interview process was at time challenging for the author due to linguistic and cultural differences, especially during phone interviews with poor sound quality. To validate the author's understanding, complementary emails were sent to interviewees themselves and a draft of the thesis was sent to all interviewees on September 6th, 2019, with the request to verify the information provided.

6.3.2 Further research

Based on the above, this section outlines axes for further academic research. First of all, further study on potential business models for repair and maintenance as well as refurbishment and remanufacturing should be conducted to confirm the findings of this research. Taking into account the limitations presented in 6.3.1, future studies could include a broader range of stakeholders and could allow a longer research period with co-creation and collaboration processes (i.e. action based research) between stakeholders, in order to facilitate the CBMI process (Bocken et al., 2019). This could allow further understanding of the repair business model components such as customer segments and associated value proposition. To cope with the focus of participants on solar PV and batteries, further research could more systematically discuss all product components of SHS and SL, including charge controllers and LEDs.

Given the growing importance of solar pumps on the off-grid solar market driven by government schemes (Gogla & cKinetics, 2019), this study could be replicated to include new product categories such as solar pumps. This would allow to compare results between SHS and SL and identify drivers, barriers or business model elements that are product dependent. Potentially, this would assist in the definition of product-specific or component-specific policy recommendations.

Thirdly, further research would need to evaluate the environmental impacts of product life extension strategies for SHS and SL. Indeed, this study took the business model dimensions as its unit of analysis and concluded that, from a business perspective, repair and maintenance services should be prioritised. However, the environmental benefits of favouring repair over refurbishment and remanufacturing need to be demonstrated by a life cycle analysis. Potential rebound effects of repair and maintenance business models would need to be identified and measured (Zink & Geyer, 2017).

Lastly, research on how such business models in the Indian market could potentially impact the development of recycling strategies in the country should be established as well as the complementarity of inner-loop strategies.

Conclusions

The objective of this research has been to investigate how circular business models could be designed to extend the product life of solar home systems and solar lanterns in India. Based on an exploratory case study, this chapter presents the conclusions of the study and proposes recommendations for practitioners and academia.

The findings show that, among the three studied product life extension strategies, repair and maintenance services for SHS and SL could more easily emerge on the Indian market. Three identified strategies to catalyse repair and maintenance services are 1) integrating a remote monitoring system into SHS, 2) providing annual maintenance contracts, and 3) enabling lithium-ion battery replacement through the supply of spare parts and change of product design. The research suggests that the creation of an Indian coalition for repair among OEMs and OESs would enable economies of scale as well as increase customers' trust in repairs and their willingness to pay for such services. In addition to repair, OEMs/OESs also have the promising opportunity to offer refurbished SHS as donations to disadvantaged communities and to conduct a pilot for collection and refurbishment of defect SHS. Lastly, remanufacturing has not been identified as an opportunity given the small manufacturing base of off-grid solar components in India.

In this context, the research proposes the integration of the four identified R&M strategies into one business model. The value proposition of this model focuses on offering reliable electricity services at lower life cycle costs, with shorter downtimes and high convenience of repair and maintenance services. This value proposition would be of interest to SHS and SL customers looking for convenience of repair services and/or looking for easy battery replacement. Its delivery relies on close OEMs/OESs customer relationships, strongly developed channels of customers services, availability of trained local technicians as well as products designed for repair including an IoT technology for remote controlling of SHS performance. In terms of value capture, business model revenue streams include lithium-ion replacement batteries sales, used lithium batteries sales to recyclers, annual maintenance contracts and monthly payment through the pay-as-you go system. This financial structure would be viable as long as revenues streams outweigh the product and services costs and enable the company to reach its required margins.

Barriers to repair strategies and business models include the non-adaptability of the product design to repair activities, the non-availability of standardised spare parts and the difficulty to provide affordable repair services to the last mile for which rural households are willing to pay. However, growing demand for repair services and the implementation of more stringent tendering requirements for R&M service monitoring in government programs would accelerate the uptake of repair business models. Concerning refurbishment, the introduction of a clear policy framework and standards defining refurbishment activities and refurbished products as well as a strong market demand for second hand SHS could accelerate refurbishment strategies in the off-grid solar sector. Numerous challenges for establishing refurbishment business models still remain. They include the difficulty to supply used products at the right quality, price and volumes, an unproved refurbishment technical feasibility, a low customer demand and inappropriate refurbishment policies and standards for refurbishment.

Recommendations for practitioners

Using an explorative case study design, this study constitutes a first step into rethinking the off-grid solar industry linear strategies and business models in the Indian context. It offers the following recommendations for practitioners in the off-grid solar industry in India as well as in international markets:

For OEMs and OESs in India and in international markets – To protect the off-grid solar industry's image and build customer trust, the research strongly suggests OEMs and OESs to further integrate repair strategies for SHS and SL into their business models as well as to engage with business model experiments for refurbishment. Influencing policymakers to remove hindering factors for circular business model innovation, via industry associations such as GOGLA, would also accelerate the CE transition in the industry.

For actors of the SWAP project –The results suggest the consultancy firm Sofies to integrate repair business models into its current roadmap for a sustainable solution for end-of-life management of off-grid solar products in India. This would influence partnered OEMs and OESs to consider and implement repair strategies into their BMs. In addition, it would encourage Sofies in evaluating the potential complementary of repair strategies with the development of its recycling blueprint in India.

For Indian and foreign policymakers – Accelerating repair and maintenance would require policymakers to strengthen government schemes tendering requirements. In addition, formalising refurbishment activities and building process standards/certifications would remove the most prohibitive factors for industry actors. Lastly, incentives for Indian off-grid solar products and components manufacturers would accelerate product design changes for repairability and disassembly.

Academic contribution and recommendations for further research

This thesis contributed to advance the current knowledge of end-of-life management of solar PV and more precisely of solar home systems and solar lanterns. Furthermore, this research highlighted that the decision of off-grid solar firms to adopt repair and maintenance strategies is influenced by a range of additional factors. These factors include the existence of tendering requirements for repair, the integration of repair into the overall business strategy as well as customers' product knowledge and the use of new technology into SHS. Lastly, the decision of off-grid solar firms to adopt refurbishment strategies is also influenced by the technical feasibility for refurbishment. Further research is needed to confirm the findings of this thesis using the same unit of analysis but addressing the methodological limitations of the study and integrating growing product categories such as solar pumps. Lastly, Life Cycle Analysis (LCAs) would validate the environmental relevance of prioritising repair and maintenance over refurbishment and remanufacturing.

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Appendix A: List of research terms used for Literature Review

	Research terms used	Platforms
Academic Literature	- Circular Economy - Repair - Refurbishment - Remanufacturing - Product life extension - Business Model - Circular (Economy) Business Model - Circular Supply Chains - Business Model Innovation - Business Model Experiments - Circular Design - Second Life/use Combined (non-systematically) with: - Photovoltaics - Solar PV - Off-grid solar products - Solar Home Systems - Solar Lanterns - Solar waste - Batteries - Developing countries - India	LubSearch Scopus.com Research Gate
Grey Literature	- Circular Economy & India - Off grid solar products & India - Solar waste & India - Resource Efficiency & India - Circular strategies & off grid solar products	Google.com

Source: Own illustration

Appendix B: List of interviewees

Interviewee	Position	Company	Type of Company	Date	Time (min)	Mean	Recording
N°1	Managing Director	X1	Solar PV recycling	04/07	60	Virtual	Yes
N°2	Representative	X2	Association	11/07	30	Virtual	Yes
N°3 & 4	Program Managers	World Bank Branch	Global Development Institution	23/07	70	Face to Face	No
Palak Aggarwal	Founder and Managing Director	Batti Ghar Foundation	Not for profit Foundation in Energy Sector	15/07	60	Virtual	No
N°5	Customer Service Operations Manager	X5	SHS and SL Original Equipment Manufacturer and Distributor	23/07	60	Virtual	Yes
N°6	Lead Indian Sub-Continent	X6	Multinational Fast Moving Electric Goods (include SHS)	16/07	75	Face to Face	No
N°7	Managing Director	Dharma Life	Off grid solar distributor	25/07	20	Face to Face	Yes
Mandvi Singh	Renewable Energy Program Manager	CSE	Research and Advocacy Institute	24/07	35	Face to Face	Yes
Rachna Arora	Deputy Team Leader & Coordinator, European Union - Resource	GIZ India	Service provider of international cooperation for international development	25/07	65	Face to Face	Yes
Ananth Aravamudan	Senior Advisor	Villgro (Past experience at Selco)	Social Enterprise Incubator	25/07	45	Virtual	Yes
N°8	Operation Manager	SELCO Solar Light Pvt Ltd.	Social Energy Enterprise	25/07	45	Virtual	Yes
Pratim Raha	Program Manager	SELCO Foundation	Not for profit Foundation in off-grid sector	26/07	65	Virtual	No
Sagar Mahap atra	Managing Director	Urjaa Samadhan	SHS and SL solution provider	23/07	75	Virtual	No
N°10	Fellow	X10	Indian Environment Research Institute	29/07	55	Face to Face	Yes
Manish Kumar Pandey	Fellow	TERI	Indian Environment Research Institute	29/07	20	Face to Face	Yes
Prodip Chatterjee	Founder	Nunam	Lithium Ion Batteries Refurbisher	06/08	35	Virtual	Yes

Source: Own illustration

Appendix C: Example of interview guideline for an OEM

1	Could you please present the core business activities of your organisation and your role in this organisation?
2	Has your organisation explored repair, refurbishment and or/remanufacturing business models of solar home systems and/ or solar lanterns?
3	In the Indian context, do you see any opportunity to create business models for repairing off grid solar products (solar lanterns/ SHS)? Why or why not?
4	How could such business model for repair be implemented in your perspective? • Activities • Customer segments & Value proposition • Resources & Capabilities • Channels • Partnerships • Costs & revenues generation
5	What are the challenges to implement repair business model in India?
6	What factors could be decisive for actors to move into repair?
7	In the Indian context, do you see any opportunity to create business models for refurbishing off grid solar products and their components (solar lanterns/ SHS)?
8	How could such business model for refurbishment be implemented in your perspective? • Activities • Customer segments & Value proposition • Resources & Capabilities • Channels • Partnerships • Costs & revenues generation
9	What are the challenges to implement refurbishment business model in India?
10	What factors could be decisive for actors to move into refurbishment?
11	In the Indian context, do you see any opportunity to create business models for remanufacturing off grid solar products and their components (solar lanterns/ SHS)?
12	How could such business model for remanufacturing be implemented in your perspective? • Activities • Customer segments & Value proposition • Resources & Capabilities • Channels • Partnerships • Costs & revenues generation
13	What are the challenges to implement remanufacturing business model in India?
14	What factors could be decisive for actors to move into remanufacturing?

Source: Own illustration

Appendix D: Coding structure on NVivo

Category	Nodes	Sub-Nodes
Repair	Barriers	• Product Design • Product Quality • Spare parts • Volumes • Supply chain structures • Business strategy • Company's willingness • Human and financial resources • Customer demand • Customer willingness to pay
	Existing BMs	• Value proposition • Value creation and delivery • Value capture
	Business Model Innovation Factors	• Business opportunity • Tendering requirements • Business Environment • Management
	Ideation for new BMs	• Repair strategies • Value proposition • Value creation and delivery • Value capture
Refurbishment	Barriers	• Product performance and quality • Volumes • Standardisation • Safety concerns • Supply of used components • Technical Feasibility • Investment • Policy & Standards • Awareness • Consumption patterns • Willingness to pay
	Existing BMs	• Value proposition • Value creation and delivery • Value capture
	Business Model Innovation Factors	• Cost • Policy & standards • Customer demand • Examples • Company's values
	Ideation for new BMs	• Refurbishment strategies • Value proposition • Value creation and delivery • Value capture
Refurbishment	Barriers	• Technical feasibility • Volumes • Manufacturing base • Investment • Supply chains structures • Customer demand

Source: Own illustration

Appendix E: Material composition of off-grid solar main components

Off-grid solar components	Materials
Solar Panels (Multi-crystalline based)	• Glass in Front Glass (74%) • Aluminum in Frame (10%) • Ethylene-vinyl acetate (6,8%) • Plastic foils in Back-sheet (3,8%) • Silicon in wafer (3%) • Glue (1,2%) • Copper (0,57%) in wires and contacts • trace elements (tin, lead, silver in contact layers)
Lead-acid batteries	• Lead, lead-oxide (65% of the weight) • Plastics • electrolyte (sulfuric acid) (10-15% of the weight)
Lithium-based batteries	*Generally:* • Graphite • various organic substances • copper • aluminum • lithium • plastics... *More precisely in positive electrode:* • Lithium cobalt oxide • Nickel cobalt aluminum • Nickel manganese cobalt • Lithium manganese oxide • Lithium-iron phosphate *More precisely in negative electrode (anode):* • Carbon based anodes: Natural graphite, artificial graphite or amorphous carbon • Lithium titanate
Cables	• Copper • Plastic (PVC or PE) • Insulation
Control devices (charge controller/inverter)	• Printed circuit boards • Solder paste • Electrical and electronic components with traces of gold and palladium • Plastics • Metals (aluminum, copper)

Source: Own illustration based from (Lighting Global, 2019; Manhart, Hilbert, & Magalini, 2018)