Development of Product Integrated PV (PIPV) Products for Rural Communities of India – An Industrial Design Approach

A Thesis

Submitted in Partial Fulfilment of the Requirement for the Degree of

Doctor of Philosophy

by

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Indian Institute of Technology Guwahati

Guwahati, Assam, India

(APRIL 2022)

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Under Supervision of

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(APRIL 2022)

Dedicated to my family and my teachers.

CERTIFICATE

The thesis presented here, ' **Development of Product Integrated PV (PIPV) Products for Rural Communities of India – An Industrial Design Approach'** by Mr. Pranav Ashok Satpute, was undertaken under my guidance and supervision. The volume of work presented here for the Degree of Doctor of Philosophy of Indian Institute of Technology Guwahati was not submitted earlier for any other degree or diploma.

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DECLARATION

I hereby declare that the work contained in this thesis entitled '**Development of Product Integrated PV (PIPV) Products for Rural Communities of India – An Industrial Design Approach'** is my own work done under the supervision of Prof. Ravi Mokashi Punekar and Prof. Avinash Shende, at the Department of Design, Indian Institute of Technology Guwahati, Assam. I hereby declare that to the best of my knowledge; it contains no material previously published or written by any other person or substantial properties of the material which have been accepted for the award of any other degree or diploma at Indian Institute of Technology Guwahati or any other educational institute, except where due acknowledgement is made in this thesis. Any contribution made to this research by others with whom I have worked at the Indian Institute of Technology Guwahati or elsewhere is explicitly acknowledged in the thesis. I also hereby declare that the intellectual content of the thesis is the product of my work, and as per general norms of the reporting research findings, due acknowledgements have been made wherever the research findings of other researchers have been cited in this thesis.

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Abstract

Energy in the form of electricity is a crucial need in the day-to-day life of humans. There are several generation technologies from which electricity is generated and distributed to the different user locations, which majorly happens through the electricity grid. In India, around 69 per cent of the total population stays in villages, and around 300 million people still have no access to basic electricity. Sparsely distributed population, uneven terrain and geographical conditions make it challenging to distribute electricity through the grid to the users residing in villages of India. Hence electrification is still one of the biggest challenges in rural India.

Solar photovoltaic energy is the renewable and viable option to address this issue. On-grid and off-grid are the two ways solar photovoltaic (PV) energy is generated and utilized. Solar energy is generated at a central location in an on-grid generation and distributed to the users through the electricity grid. In another way, solar energy is generated and utilized where it is required in an off-grid generation. Off-grid generation does not require planning at the national level; also, it is associated with the limited capital requirement and easy access to rural and remote communities of India.

Product-integrated photovoltaic (PIPV) refers to the products and systems in which the solar panel is integrated into a product's casing or another surface. There is the use of energy generated by PV cells for the energy requirement of the product during its function. Such products directly interact with their user and primarily aim for grid-independent applications, making them ideal for use in rural and remote areas associated with the lack of access to electricity.

Industrial design is a strategic problem-solving process that drives innovation, builds business success and leads to a better quality of life through innovative products, systems, services and experiences. It will play an essential role in envisaging the new applications of solar PV energy through PIPV product interventions to fulfil various electricity needs of India's rural population. The research study acts at the intersections of three main pillars; PIPV, Industrial design and the needs of rural communities of India.

Considering the phases involved in designing PIPV products to address the various needs of the users from the rural communities of India, the research study is divided into three sub-studies which address the respective research questions to find insights in each phase. Based on the earlier literature, field studies and case studies, the opportunities and critical areas for the Intervention of PIPV products are identified. PIPV Product interventions available in the market, Grassroot innovations and attempts to innovate are identified to map them based on the user needs to be addressed by them. At the same time, the open-ended design Exercise is conducted with industrial designers to understand the interventions conceptualized by them, which are also mapped to identify the addressed user needs. This study identifies the crucial needs of the users to focus on for the PIPV product intervention. In the next phase, the process of design and development of the PIPV product is observed and studied through scenario-based design experiments with industrial designers. The need for an active feedback system and an interface between various stakeholders associated with various phases of PIPV product design is realized. Also, the transition of the PIPV product from its ideation phase to the realization phase is observed. During the entire research, to evaluate the PIPV product with its users from rural areas, the spiderweb evaluation model was adopted and tested to evaluate the PIPV interventions and identify their improvement areas. Based on all the findings, the approach for designing and developing PIPV products in rural India is proposed, which is then validated through the design, development and field testing of PIPV insecticide/fertilizer spraying equipment for agricultural use.

Research explores Industrial Design as an intervention area and focuses on PIPV products in the context of Rural India. As there are limited studies that address these three aspects together, the research contributes by generating new knowledge which will help Industrial designers, Design Engineers, and Product executors who are willing to design PIPV products for rural communities in India.

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Abbreviations Used in the Thesis

3D	Three-Dimensional
AM	Amplitude Modulation
CAD	Computer-Aided Design
DC	Direct Current
EHP	Electron Hole Pair
FM	Frequency Modulation
GYTI	Gandhian Young Technological Innovation
GW	Gigawatt
HP	Horsepower
INR	Indian Rupee
IoT	Internet of Things
LED	Light-Emitting Diode
Li-ion	Lithium-Ion
NGO	Non-Governmental Organization
NIF	National Innovation Foundation
OEM	Original Equipment Manufacturer
PHC	Primary Health Care
PIPV	Product Integrated Photovoltaic
PLA	Polylactic Acid
PV	Photovoltaic
RE	Renewable Energy
TED	Technology, Entertainment, Design

CHAPTER 1

Research Introduction

Chapter one briefly introduces the research topic 'Development of Product Integrated PV (PIPV) Products for Rural Communities of India – An Industrial Design Approach'

The three pillars that drive the enquiry of this study are the Industrial Design process, the development of PIPV technology-based products and considerations of needs and lifestyles relevant to a rural Indian context. Justifying the case for the wide scope for intervention, the chapter highlights that the Industrial designers in India have not made any serious attempt to contribute with well-designed PIPV products appropriate for the rural needs of the community.

This chapter defines the research's motivation, scope, aim, and objectives, considering the three pillars of inquiry. It outlines the broad coverage of the research in the different chapters covered in this research study.

1.1 Introduction

Energy in the form of electricity is a crucial need in the day-to-day life of humans. Currently, electricity is generated at a central location and distributed to various parts of the country through the electricity grid using multiple technologies. This distribution has many challenges for a majority of the population lives in remote villages and remote geographical areas in India. Sparsely distributed population, uneven terrain, and geographical conditions make it challenging to distribute electricity through the grid to the users residing in villages. However, as around 70 per cent of the total population of an agrarian India stays in villages, it is essential to explore possibilities to generate grid-independent electricity to fulfil people's daily needs in rural places and remote areas. Solar photovoltaic (PV) energy is a renewable and viable option that needs to be explored through Product integrated photovoltaic (PIPV) product interventions to fulfil the electricity needs of the rural population. Being a strategic problem-solving process, Industrial Design can play an essential role in envisaging the new applications of solar PV energy through PIPV Product interventions to fulfil various electricity needs of India's rural population. There are three significant aspects of this research: rural context, PIPV product development, and Industrial design. These are the three pillars of this study. Each domain is described individually so that the reader understands how they are related to the research's overarching common purpose.

1.2 Area of Research

The research focuses on three pillars: Product Integrated Photovoltaics (PIPV), Rural India, and Industrial Design. Research is framed to act at the intersection of these three pillars. The main focus of the study is on the development of the industrial design process for the development of Product Integrated Solar Photovoltaic products for rural context of need.

There are various sources of energy categorized as conventional and renewable sources. Due to the depletion of traditional energy sources, the world is rapidly adopting new and renewable energy in the current energy scenario. Solar, Wind, Hydro, and Geothermal are the primary renewable energy sources. Solar energy gets utilized in thermal and photovoltaic ways of conversion. Again, it has grid-connected and off-grid uses in which grid-connected generation is centralized. In contrast, off-grid generation is helpful in the scenario where the expansion of the grid is expensive and sometimes technically complex to realize. Off-grid Photovoltaics can be considered BIPV - Building Integrated Photovoltaics -in which solar panels are integrated with building architecture, and PIPV - Product Integrated Photovoltaics - where PV panels are integrated with products.

Looking at all these energy sources, solar PIPV is associated with products with direct interaction with users, bringing industrial design attributes like usability, ergonomics, and aesthetics into consideration that impact their acceptance and commercial success.

In India, even today, a significantly large population, nearly 3 million people, live in remote villages, and some of them still have very poor or no access to electricity. Often in rural areas where expanding the national power grid is too expensive, PIPV can be effectively used in India's rural and remote areas to fulfil the energy (electricity) needs of various activities (Chandramouli, 2016). Meeting these challenges deals with creativity, innovation, and user-centred thinking; Industrial Design could play an essential role. Figure 1.1 shows the area of research.

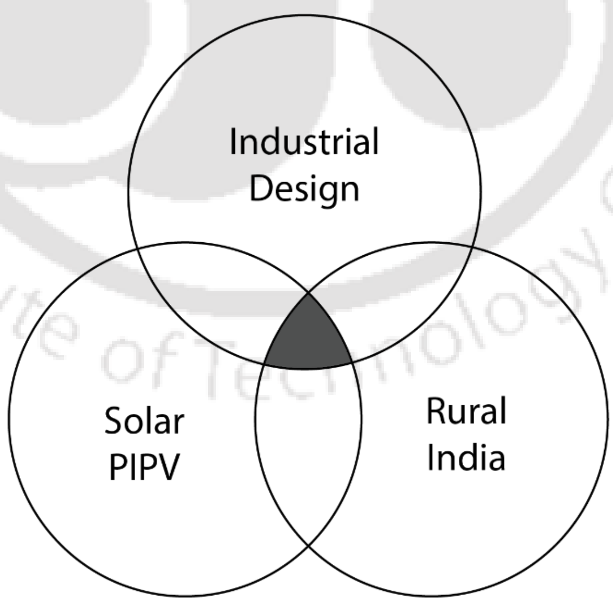


Figure 1.1 Area of research

This research study focuses on developing a suitable design process for developing PIPV products that factor overarching consideration at the intersection of Solar PIPV product development for the Rural context of needs in India driven by Industrial Design processes. These three pillars are elaborated in subsequent sections to get an overall idea about the research context, focus, and direction.

1.3 Solar PIPV Technology

Solar photovoltaic energy is a clean, renewable energy source that uses solar radiation to produce electricity. It is based on the photoelectric effect, by which certain materials are able to absorb photons (light particles) and release electrons, generating an electric current. Centralized generation of solar energy is associated with its distribution to the users through the electricity grid. Considering the sparsely distributed population, uneven terrain, and transmission losses, it is challenging to expand the grid to many rural and remote places of India (Urpelainen, 2014). Decentralized off-grid supply based on off-grid solar photovoltaic technology has emerged as a potential solution to grid connectivity problems in rural India's energy-poor communities (Millinger, Mårlind, & Ahlgren, 2012). The abundant availability of solar energy in India, which has an average of 300 clear sunny days annually (Agoramoorthy & Hsu, 2009), provides a solid foundation for a viable implementation of off-grid solar PV intervention. The decline in the cost of solar products (Harish, Iychettira, Raghavan, & Kandlikar, 2013), user-friendly technologies and standalone decentralized form of distribution make it a feasible option. Product-integrated photovoltaics refers to the products and systems where the solar panel is integrated into the system. The integrated PV panel provided the electricity required for the functioning of that particular product. It primarily aims at the grid-independent applications of solar energy (Angelina H M E Reinders & Van Sark, 2012). Being grid-independent and standalone systems, PIPV has the potential to fulfil the electricity-related requirements of the people staying in rural and remote places of India where there is limited or lack of access to electricity grid. PIPV products are the focus area of the research with the context of its applications in rural India.

1.4 Rural India: the need for PIPV product interventions.

As per the census of India 2011 data by the government of India, Rural areas are defined as the areas having a population density of less than 400 per square kilometre, 75% of males working are involved in Agricultural and allied activities, and the village as a unit is without any presence of Municipal board. Figure 1.2 shows the total number of villages and towns with the rural-urban distribution of the population (CHANDRAMOULI, 2011).

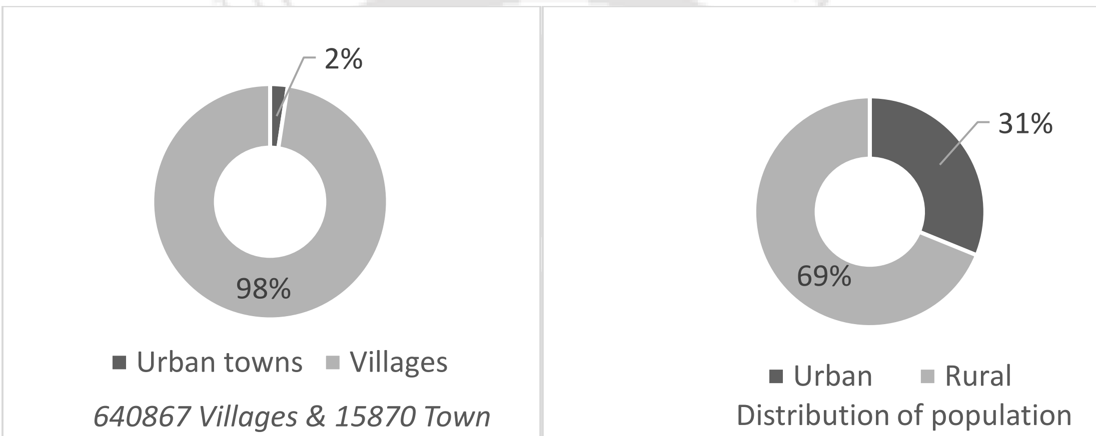


Figure1.2 Number of villages and distribution of the population of India

In India, there are around 640867 villages which comprise about 98 per cent of the total number and 15870 towns which is 2 per cent of the total number. Also, nearly 70% of India's population lives in villages. Around 300 million people still have no access to basic electricity (Singh, 2016) (Shukla, Sudhakar, Baredar, & Mamat, 2018), often in rural areas where expanding the national grid is too expensive. There are several issues like the cost of expansion of the grid, hilly terrain and transmission losses, etc. Off-grid solar energy is an option to counter this issue. There are various activities of people staying in rural places which depend on electricity that can be performed through off-grid solar energy interventions.

1.5 Industrial Design

At the 29th General Assembly in Gwangju (South Korea), the Professional Practice Committee unveiled a renewed definition of industrial design as follows:

> 'Industrial Design is a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences.'

An extended version of this definition is as follows:

> 'Industrial Design is a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences. Industrial Design bridges the gap between what is and what's possible. It is a trans-disciplinary profession that harnesses creativity to resolve problems and co-create solutions to make a product, system, service, experience, or business better. At its heart, Industrial Design provides a more optimistic way of looking at the future by reframing problems as opportunities. It links innovation, technology, research, business, and customers to offer new value and competitive advantage across economic, social, and environmental spheres.' (ICSID, 2015)

Industrial Designers place humans at the centre of the process. They understand user needs through empathy and apply a pragmatic, user-centric problem-solving approach to design products, systems, services, and experiences. They are strategic stakeholders in the innovation process and are uniquely positioned to bridge varied professional disciplines and business interests. They value their work's economic, social, and environmental impact and their contribution to co-creating a better quality of life (Howell et al., 2016) (ICSID, 2015)

When solar panels are integrated with products, it is called product-integrated photovoltaics (PIPV). PIPV is associated with products that involve direct user interaction, and hence their development needs to be considered from the perspective of Industrial Design. PIPV can be effectively used to solve associated problems through innovative product iterations. Industrial designers can produce innovative concepts to solve problems by exploring PV technology creatively. As this technology is new to the users and industrial designers as well, it is equally important to study and understand the process of industrial design while dealing with PV technology in rural India

1.6 Motivation for the research

At the beginning of the 20th century, Mahatma Gandhi emphatically declared:

"The soul of India lives in its villages," – Mahatma Gandhi

Even after seventy-four years of Independence, villages are at the core of the country's soul. A large population of India continue to stay in villages. However, many of these villages lack or receive an intermittent supply of electricity. It affects the daily life of people, including various activities related to education, agriculture, healthcare and household.

In a large and diverse country like India that follows a mixed economy, the challenges in setting the development agenda for economic growth are faced with a complex web of socio-economic and cultural considerations. Power generation is one of the engines for economic growth along with infrastructure development. While industrial growth is witnessed among the different sectors of industry, the focus on agriculture and the rural sector cannot be wished away as the country's economy is predominantly an agrarian economy. Planning for an inclusive approach that meets the challenges of growth, on the one hand, creation of employment and poverty elevation are challenges that are to be met concurrently and in a balanced manner.

The literature review has clearly indicated the economic difficulty of facilitating power to remote rural and difficult to access villages in the country. Off-grid modes of power generation are perhaps the only viable means to empower these communities. The development of improved battery storage technologies and Photovoltaic technologies seems an economically sustainable and viable means to meet these challenges. The emerging focus on incentivizing sustainable industrial development on a priority basis in meeting global sustainable development goals has set a renewed focus on PV in the country. Therefore, intervention in the agriculture sector through intervention with PIPV-based product interventions is timely. These current developments are the motivation for this research study.

It was further strengthened by a conviction of the personal experience of this researcher. He first grew up in a village in Maharashtra and has experienced village life. Higher education, first in Engineering, took him to the city, followed by pursuing a Masters in Product Design at IIT Guwahati motivated him to pursue this research for his doctoral degree in Design. This learning curve has led to much questioning of why there is so little initiative on the part of trained industrial designers to intervene and contribute to the challenges of product design and development that address and meet the needs of rural India. There are very few products developed by trained professional industrial designers in India. Why are there so few well-designed products for rural context developed by industrial design intervention?

The researchers continued periodic interactions with rural community members, closely and critically reviewing the lifestyle with a trained designer's lens of everyday activities in the village among his rural community members, resulting in setting the focus for undertaking this research in PIPV product development for rural communities in India.

Further, considering the inputs given in the current academic programs in industrial design led the researcher to question if the present industrial design program provides adequate inputs to train prospective designers and design engineers engaged in the design of PIPV products, considering the prospects that rural India offers. Phillip Jennings (2009) makes a critical observation that most engineers are not trained to use renewable energy technologies, and many are unaware of sustainability principles. In his article, 'New

Directions in Renewable Energy Education',(Jennings, 2009), he makes an urgent plea to develop and implement new courses that prepare engineers, scientists, and energy planners to work with renewables to produce sustainable energy generation systems that promise to impact society and the environment. There are clear markers of a fundamental shift in the energy market that requires that a new class of trained professionals be exposed and made aware of these latest technologies and the manner in which they impact the social, economic and environmental parameters. One of the needs of Renewable Energy Education is to provide well-trained tradespeople who can design, produce and maintain reliable and cost-effective systems.

We believe the involvement of industrial designers in the development of innovative PIPV product solutions can fulfil some of the basic electricity needs of rural communities. The need for PIPV product interventions to improve the quality of life of the people staying in remote and rural places of India motivated us to conduct research in this domain.

1.7 Research questions

Various studies conducted in this research are based on the research questions that help decide the flow of research. Below are the enquiries and associated research questions based on which research is conducted

Enquiry 1. What are the potential areas of intervention for PIPV products in rural India, and what are the needs of users that designers should consider?

> **Research Question 1:** What are the crucial electricity-dependent needs of people which can be addressed through PIPV product interventions by designers?
> **Research Question 2**: What are the available PIPV interventions in the market, and what user needs they are addressing?

Enquiry 2. What are the challenges in developing PIPV products; the type of support and input information required for Industrial designers in each phase of PIPV product development?

Research Question 3: What factors affect the industrial design process of PIPV products, and is there any support required for it?

Research Question 4: How does the PIPV product transform from the ideation phase to the realization phase with the input information and support in each stage of development?

Research Question 5: What evaluation model can be adopted to evaluate the PIPV products in a rural context?

Enquiry 3. What should be the possible approach to proceed with the Industrial design and development of PIPV products in a rural context?

1.8 Aim and Objectives of Research

The research aims to identify the possible approach for the industrial design and development of PIPV products for rural communities of India. It is achieved through various studies, experiments and development iterations of PIPV products for the users.

The research study is conducted with the below objectives

a) To identify the possible **intervention and focus areas** for the **design interventions in PIPV** considering the **needs of rural communities of India**

b) To study the **PIPV product design and development process** and **identify the challenges and support required for the designers** during each phase of development.

c) To define and validate the **approach for Industrial design and development of PIPV products** for rural communities of India.

1.9 Outline of the Thesis Report

The thesis is divided into seven chapters, and various topics covered under each chapter are described in table 1.1

Table 1.1 chapters of thesis and various topics covered under them

Chapter Number	Chapter Title	Chapter description
Chapter 1	Research Introduction	Chapter one gives a brief introduction to the research topic with the focus area and context of the study. As the research focuses on three different aspects considered the three pillars of study, this chapter elaborates on each of them to get insight into the overall research flow. This chapter defines Research motivation, scope, aim, and objectives.
Chapter 2	Literature Review	Chapter two elaborates the extensive literature search around the research pillars to get insights into the facts, figures, and earlier interventions and theories.
Chapter 3	Research Design	Chapter three of the thesis outlines the design and methodology of the research. It defines the flow and direction of research to achieve the aims and objectives of the research
Chapter 4	Design For Rural India - Opportunity Mapping for Industrial Design Interventions of PIPV Products, Design and Development of PIPV	This chapter describes the insights gathered from case studies and field visits to villages of Maharashtra and Meghalaya states of India. The study described in this chapter dives into the interventions in PIPV and analyses them to identify the respective user needs to be satisfied by them. This study addresses the elaborative level of design research.

Chapter 5	Ideation to Realization: Transition of PIPV product concept	Chapter five covers the journey of the PIPV product concept from the ideation phase to the realization phase. The feasible concept from the design experiment is developed in an actual working prototype of the product, which is then tested with the users in the actual environment to take their feedback. This process gave insights into the challenges and barriers in the industrial design and development process of PIPV products conceptualized for use in a rural context.
Chapter 6	Approach for the development of PIPV products in the context of Rural India – Application of findings	Based on the findings, the step-by-step approach for the industrial design and development of PIPV products is proposed and validated through the development of PIPV product which is then tested in the field to evaluate based on user feedback. This chapter describes the design, development and testing process of PIPV products based on the proposed approach.
Chapter 7	Conclusions	This closing chapter of the thesis covers the discussion and summarizes the findings from various research studies along with the research's contribution, future scope, and limitations.

In addition, the various annexures and references placed at the end of the chapters complement the research work

1.10 Chapter summary

Around 70 per cent population of India stays in villages, and the majority of them are associated with a lack of or intermittent supply of electricity. The primary reason behind this is the difficulty in expanding the national electricity grid to these regions because of various factors like sparsely distributed population, uneven terrain and geographical conditions. It affects people's lives staying in those regions as electricity is crucial in daily activities. Solar photovoltaic technology with product-integrated photovoltaics (PIPV) refers to the products in which solar PV panels are integrated into the product to supply electricity to perform its function. These products are grid-independent and can be significantly used in regions associated with a lack of electricity. Industrial design will play a crucial role in envisaging the new application of solar photovoltaic energy through PIPV product iterations to fulfil people's daily needs. The area of research with associated three pillars, Industrial Design, Rural India, and solar PIPV, are described in this chapter with the formulation of research questions, aims, and objectives.

CHAPTER 2

Literature Review

Chapter two elaborates the extensive literature search around the research pillars to get insights into the facts, figures, and earlier interventions and theories. Published researched articles, books and relevant research documents are identified and analyzed to create the research background.

2.1 Introduction

The scope of this research rests at the intersection of three pillars that drive the search for developing appropriate design methodologies that integrate, viz. Industrial Design; development of PIPV technology-based products and their appropriate use for rural village needs in India. In Chapter Two, we undertake a state of art literature review considering earlier interventions and theories in the above three domains. The sources of our references include published researched articles, books and relevant research documents identified and analyzed to create the research background and assist in determining the directions for planning our experimental methods that address our research questions.

To begin with, this review focused first on understanding the domain of PV technology and the scope, importance, and potential of solar energy in the context of rural India. This is followed by a review of the developments in industrial design, their methods and current contributions in the design development of PIPV products for users located in rural and remote places of India. This review aimed to identify the potential areas for effective intervention that would set the directions for product design development, enabling more effective, longer-lasting PIPV products. Figure 2.1 shows the areas explored for the literature review.

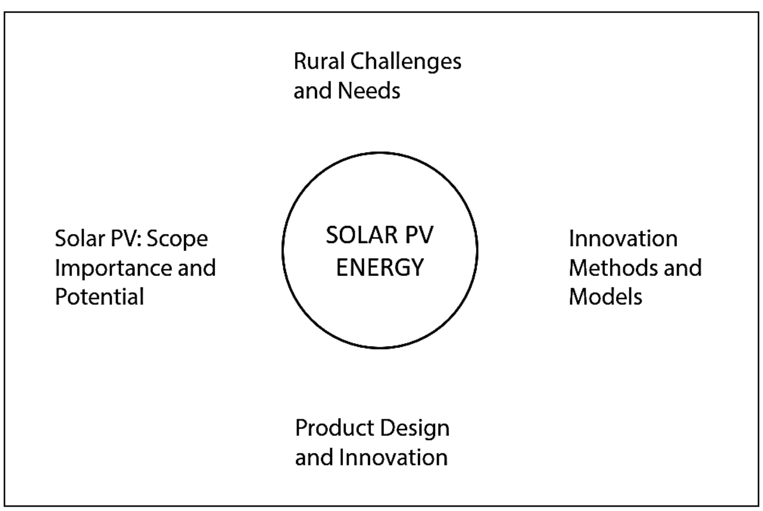


Figure 2.1 Areas for literature review

2.2 Solar energy - potential and scenario: An overview

Energy is a basic need in our everyday life. Currently, energy used by us is in various forms, out of which electricity is the major contributor. Due to the depletion of conventional sources of electricity and its associated hazards to the environment, renewable energy sources have started taking the place of traditional sources. Solar photovoltaic is one of the renewable sources of energy that is inexhaustible, comparatively clean, and freely available. Theoretically, solar energy possesses the potential to adequately fulfil the energy demands of the entire world if technologies for its harvesting and supplying were readily available (Blaschke, Biberacher, Gadocha, & Schardinger, 2012). Solar energy can provide solutions to the longstanding energy problems being faced by developing countries like India. For the entire world, it is expected that solar energy will represent the second-largest power source behind wind power, generating 25% of the world's power; and Solar photovoltaic power will be a significant contributor to total solar power production (Pedraza, 2020). Day by day world is adopting solar energy, and the current installed PV capacity of the world is 627 GW[1] , out of which 115 GW was added just in the year 2019. For solar photovoltaics, India stands as the second-largest market in Asia and third-largest globally, which added an estimated 9.9 GW in 2019 for a total of 42.8 GW (Members, 2020).

2.2.1 Solar Photovoltaic Energy

The solar energy concept is regarded as the harvesting and utilization of light and heat energy generated by the sun. There are technologies that are either passive or active to achieve such goals. Table 2.1 shows the classification of current solar energy technologies (Kabir, Kumar, Kumar, Adelodun, & Kim, 2018). Passive technology involves accumulating solar energy without transforming thermal or light energy into any other form (for power generation, for instance) (Sun & Wang, 2016). The heating of homes and spaces, especially during winter, by collection, storage, and distribution of Solar energy in the form of heat is a typical example of passive solar technology. On the other hand, an

[1] GW: Gigawatts is the unit of power. 1 Gigawatt = 1000 Megawatts,

active solar system collects solar radiation and uses mechanical and electrical equipment for the conversion of solar energy to heat or electric power. Solar water heating system is a typical example of this system.

Table 2. 1 Classification of current solar energy technologies (Kabir et al., 2018)

Passive Solar Technologies	• Direct Solar Gain • Indirect Solar Gain • Isolated Solar Gain
Active Solar Technologies	• Photovoltaic • Solar Thermal • Concentrated Solar Power

In general, active solar energy technology can be further grouped into two major categories: (i) photovoltaic technology and (ii) solar thermal technology (Herrando & Markides, 2016). In recent years, photovoltaic technology involving the use of semiconductors to convert sunlight directly into electrical energy has become a highly desirable option (Mohanty P., Muneer T., Gago E.J., 2016). Solar photovoltaics contributes a significant amount of total energy produced through various solar technologies.

The photovoltaic effect was discovered in 1839 by Edmund Bacquerel, a French scientist (Fraas, 2014). Due to this effect, sunlight can be converted into electricity. Sunlight is composed of photons which are packets of energy. These photons contain various amounts of energy corresponding to different wavelengths of light. When photons strike a solar cell, a semiconductor P-N junction device, they may be reflected, absorbed, or pass through the cell. Absorption of a photon into the solar cell[2] results in the generation of electron-hole pair (EHP). When separated from each other across the P-N junction, this EHP results in the generation of voltage across it, which can drive the current in the external circuit. Therefore power can be extracted from the solar cell (C. S. Solanki, 2015). Solar cells are devices that convert solar energy into electrical energy by the photoelectric effect. Solar

[2] Solar cell is also referred as Photovoltaic (PV) Device

cells are packed into photovoltaic modules arranged in multiples to form solar arrays used in solar power generation units. Figure 2.2 shows the schematic of the photoelectric effect.

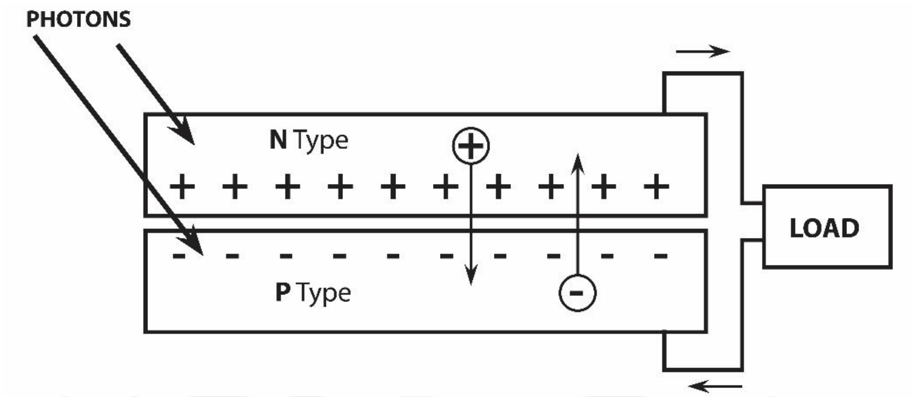


Figure 2.2 Photoelectric Effect

2.2.2 On-Grid and Off-Grid Solar Photovoltaic Energy

Solar energy is harvested in two approaches: centralized and distributed or decentralized generation. Centralized energy supply involves large-scale electricity generation at a central generation facility. This generated energy is distributed to the users through national grid connections. Figure 2.3 shows the basic concept behind the centralized generation and distribution of solar energy.

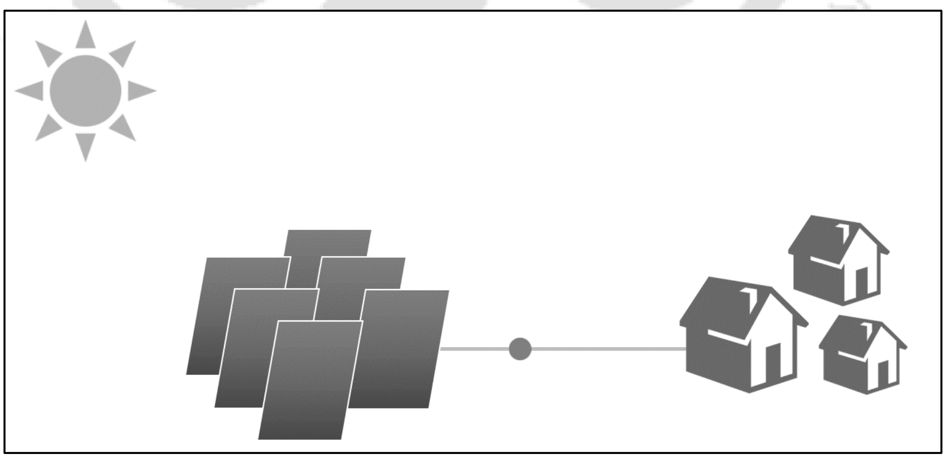


Figure 2.3 Centralized Solar PV energy

In a centralized generation,[3] electricity is generated at central power plants that are sometimes located hundreds of miles away from the 'load centre' where the customers are located. Hence, it suffers from significant energy loss in transmission and distribution (Chakrabarti & Chakrabarti, 2002). In countries like India, expanding the grid to the sparsely distributed population of remote and rural areas is difficult due to various issues like terrain, distribution network cost, etc. (Urpelainen, 2014).

Distributed or decentralized solar energy is the opposite of centralized generation. In a distributed generation, energy is generated off the primary grid and produced close to where it will be used rather than at a large plant elsewhere and sent through a national grid. For example, a simple off-grid electrification project could deploy solar panels and generate electricity for the domestic needs of households in a small community (R. P. Saini & Sharma, 2010), as shown in figure 2.4. The advantages of off-grid solar PV electrification comprise a lack of dependence on planning at the national level, limited capital requirements, and easy access to remote rural communities. A wide variety of organizational models are available for off-grid electrification, including self-generation by end-users, community microgrids, and the development of charging stations to charge batteries (Zerriffi, 2011).

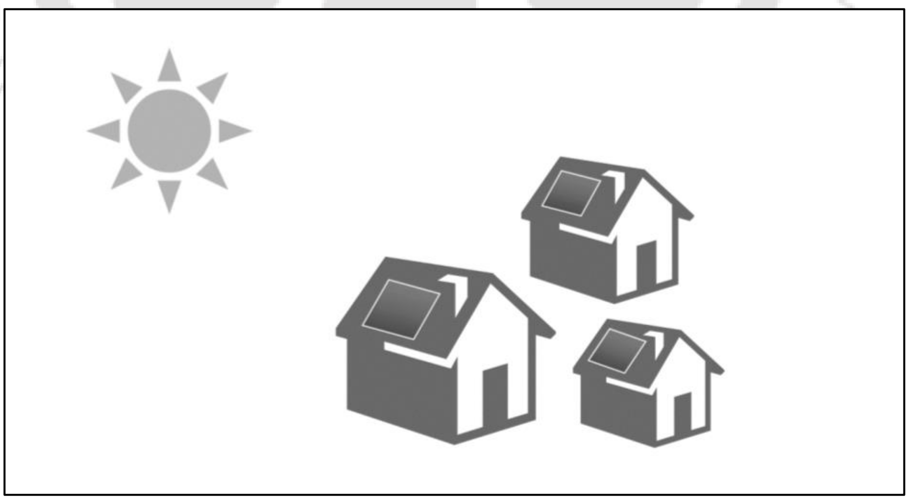


Figure 2.4 Off-Grid solar PV energy

[3] Centralized and decentralized energy generation is also termed as a On-grid and Off-grid generation respectively. For the thesis purpose decentralized energy generation is termed as Off-Grid solar energy.

Although both centralized and distributed technologies are needed to solve the rural electrification problem, this study only addresses distributed electrification. Figure 2.5 shows the transmission towers of On-Grid generation, and figure 2.6 Shows solar panels installed on the rooftop of households in Maharashtra state, India.

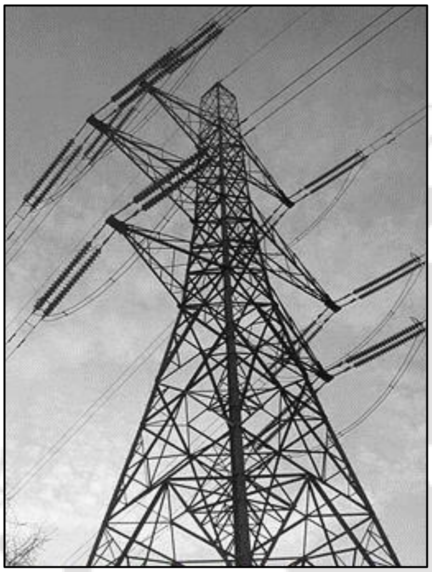


Figure 2.5 On-Grid Transmission Tower

Figure 2.6 Rooftop solar panel off-grid

Distributed solar power generation includes products categorized into public, domestic, and rooftop applications. India’s current off-grid installed PV capacity is significantly less than the country's total installed PV capacity. It shows that there is minimal adoption of solar-powered products by users. Behind this, there are specific issues like price trends and government policies, and apart from these issues, Technology and Design Innovation will play a significant role in driving off-grid solar market growth in India (Jolly, Raven, & Romijn, 2012) (Solarmango, 2014)

2.2.3 Product Integrated Photovoltaics (PIPV)

Off-grid applications of Photovoltaic technology bring product-integrated photovoltaics (PIPV) into the picture. Product-integrated photovoltaics refers to the products and systems where the solar panel is integrated into the system. It primarily aims at the grid-independent applications of solar energy. PIPV products meet the following criteria (Angelina H M E Reinders & Van Sark, 2012).

1. PV technology should be integrated into the product; that is, it should be positioned on the surfaces of the product.
2. The energy generated by the PV cells is used for the functioning of the product.
3. Users directly interact with the product in different scenarios of use.
4. Energy can be temporarily stored in a battery or other storage medium.
5. The product is applied in a terrestrial setting.
6. Often, the product has mobile or portable features.

Figure 2.7 shows the PIPV Products, solar PV lantern and table lamp.

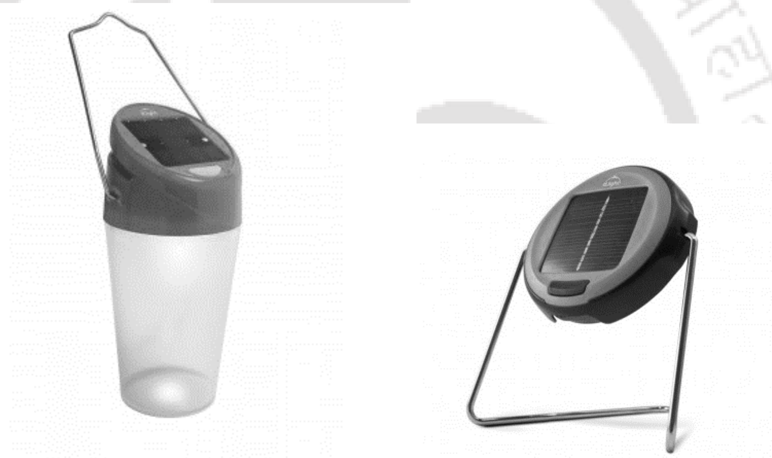


Figure 2.7 PIPV products, Solar PV lantern and table lamp (d.Light, 2020)

The main difference between PV systems and PIPV is that PIPV comprises product parts like casings and PV system components. Furthermore, while the primary function of PV systems is to generate power, the functionality of PIPV is embedded in a product context. PIPV provides functions that require electricity, for instance, lighting, sound, or transportation. Moreover, users can interact with PIPV by scenarios of use; users impose load patterns on PIPV, affecting the frequency at which solar cells are exposed to irradiance sources. Finally, products usually have a shorter lifetime than energy systems. Consumer products will be used for a few years, whereas PV systems are meant to survive life spans of at least 20 years without dramatic failure (A H M E Reinders & Sark, 2012).

The criteria for PIPV mentioned above make it suitable for application in rural and remote areas. The scope of the thesis is limited to PIPV products. It defines the first pillar of research; figure 2.8 Shows the focus of research on PIPV products.

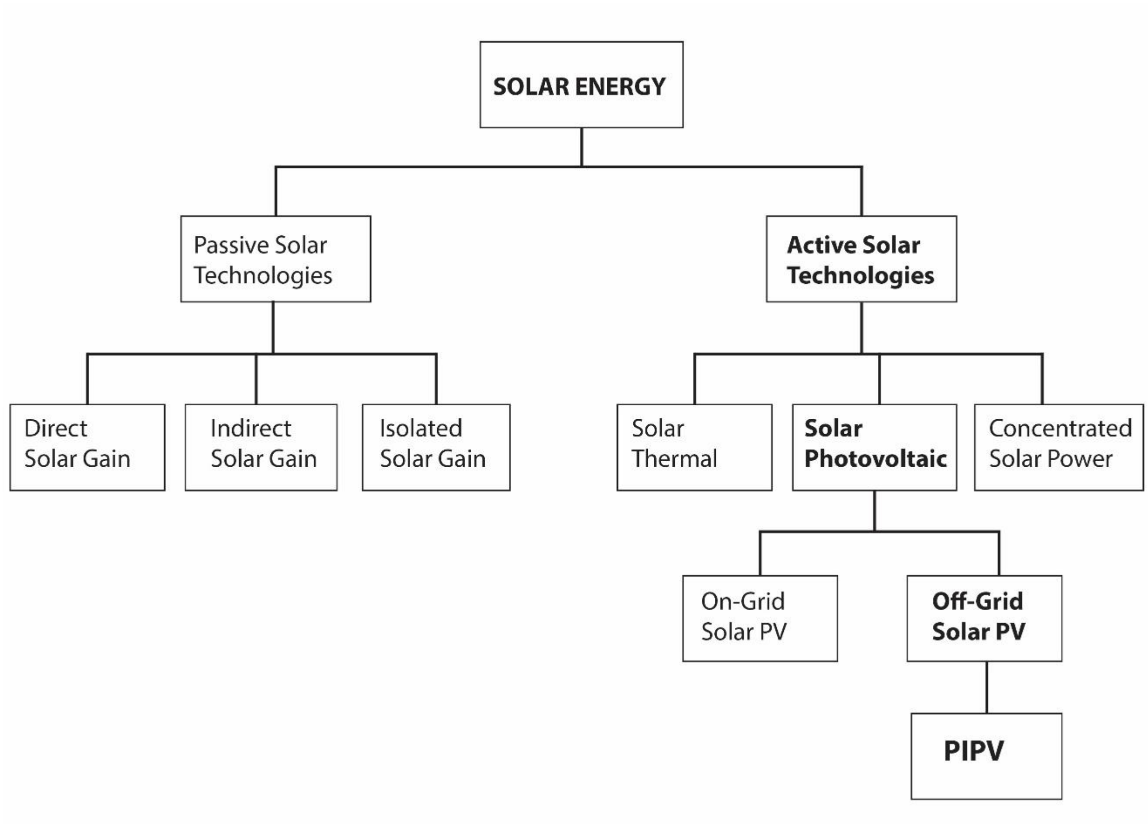


Figure 2.8 Focus of research on PIPV (First pillar of study)

As the study revolves around the primary area of industrial design, there are specific characteristics associated with PIPV products that define the scope for Industrial design interventions in rural applications.

2.3 Solar photovoltaic power for Rural India

Nitin Saini and Kumar Krishen, in their study of Innovative solar power technology systems for rural India (2015), identified the key areas and possible intervention of solar photovoltaic energy in the scenario of rural India. Their study describes the development of innovative solar-powered based systems for use in rural communities of India. They mentioned that the cost and reliability of the supply of these energy sources had been a source of concern throughout rural India. The environmental impact of their use has also surfaced as a significant concern. On the other hand, technologies for solar energy's direct and indirect benefits have progressed sufficiently to make this form of energy practical and economical for rural India (N. Saini, Jain, & Krishen, 2015). Solar energy's intelligent and innovative uses will render cost-effective, reliable, and environmentally friendly solutions for rural India. Figure 2.9 shows some needs for solar PV in rural India.

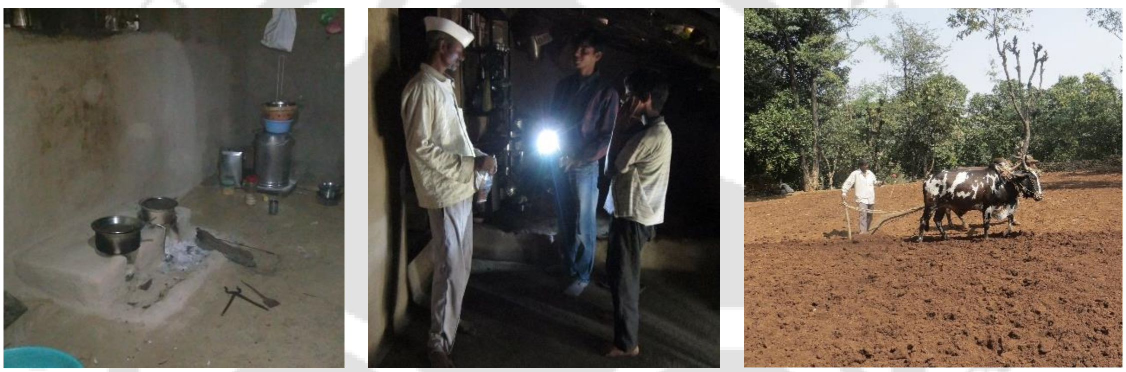


Figure 2.9 Need for Solar PV in rural India.

The rural solar power needs have not been adequately researched. Solar power applications should include direct utilization of light, heat and the transfer of solar energy into electric power. From their observations and experience, they identified rural needs, which include: Solar-powered community well; Solar-powered centralized food preservation facilities; Solar powered water wells; Solar lighted streets/corners/Farm ways; Solar-powered rural homes/Huts; Solar powered (mobile) tools/implements; Solar power booster for mobile communications; solar-powered vehicles; and Solar-powered waste management systems (N. Saini et al., 2015). This study highlights the opportunities and importance of the design and innovation of solar photovoltaic products in meeting various needs of rural India.

The study by Chetan S. Solanki et al. (2010) titled 'Strategies to target rural PV market in developing countries - a perspective' describes the solar PV market regarding products like solar lanterns, home lighting systems, and power packs, especially in the rural context of developing countries. This study is based on a marketing and economic perspective. It proposes various strategies to target the rural PV Market, including first targeting the rural rich and then building on infrastructure to reach the base of the pyramid users (Chetan S. Solanki & Mudaliar, 2010).

'Empowering rural India the RE way: inspiring success stories' (2012) is a publication of the Ministry of New and Renewable Energy, Government of India. It includes case studies about innovative interventions in solar photovoltaic technology in the rural scenario. This book highlights significant issues that India is faced with – estimating that 364 million people live without access to electricity, and 726 million people rely on biomass for cooking (Jain, V. K., & Srinivas, 2012). It indicates the need for enormous efforts to ensure energy access for all. Expanding energy access to poor households in rural and remote areas is a complex development challenge. There are limitations to the supply of electricity through the grid. There are constraints to providing acceptable and affordable solutions to meet energy requirements, especially in rural and remote areas. A part of the gap is known to be completed using diesel and kerosene, which are exhaustible and highly subject to volatility in availability and costs. Using inefficient energy conversion devices such as traditional cookstoves results in indoor pollution and causes stress on natural resources. So, there is considerable scope for renewables in bridging this gap (Jain, V. K., & Srinivas, 2012). The need for innovation in rural and remote areas can be fulfilled by involving designers to address the associated issues.

These studies give a direction for research to explore PIPV products through industrial design interventions that concur with some successful international studies that highlight the impact of off-grid solutions on local rural, and regional development. Río and Burguillo, in a study (2009), report the success of PIPV intervention that has resulted in creating new livelihood opportunities, setting up domestic enterprises, and creating local industries (del Río & Burguillo, 2009). James Nakatana's (1999) study reports creating new employment opportunities for generating additional income by extending more business hours. There is mention of an engaging social dimension whereby off-grid electricity has helped children study in evening hours, and women do more household work

(Wamukonya & Davis, 2001); Youm et al. (2000) highlight the contribution of off-grid electricity towards increased socializing (Youm, Sarr, Sall, & Kane, 2000).

In the section to follow, we examine the literature to study the intervention made in the innovation of PIPV product development.

It is essential to establish a connection between solar PV technology and new product development and identify the scope and challenges of Industrial Design intervention in contributing to enhanced user experience and commercial viability of the developed products.

2.4 Challenges faced by Designers in PIPV Product Development

In the product design process, it is generally established that the conceptual design phase is one of the critical stages of development in the product's overall lifecycle (Hsu & Woon,1998). Nearly 80% of the product cost is dictated by decisions made during the conceptual design phase (Lotter, 2013). Figure 2.10 shows the stages of the product design process.

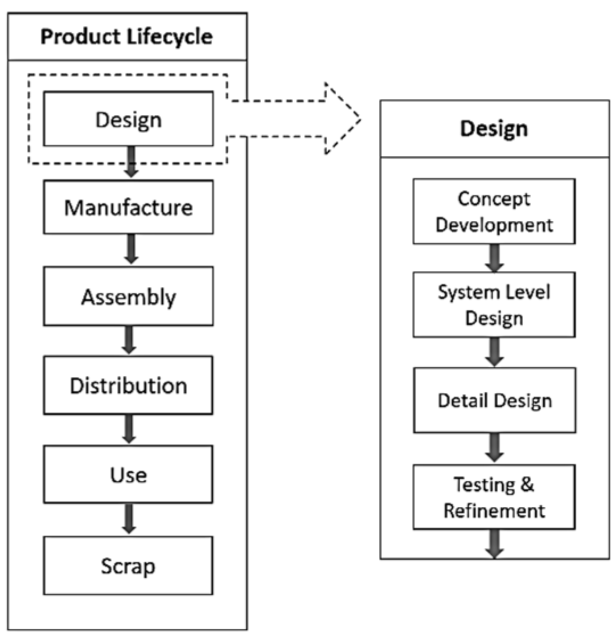


Figure 2.10 Stages of product lifecycle and design (Hsu & Woon, 1998)

It implies that during the product conceptualization stage, the designer is expected to be reasonably well informed on various aspects of the technology, the materials, processes, technical feasibility and economic consideration to make informed decisions in the conceptualization of the product or product system. Poor conceptual design can never be compensated for by well-detailed design. So, it is essential to consider the concept generation phase as critical while thinking about the life cycle of any product (Hsu & Woon, 1998).

Further, in another study, 'Towards a Selection Method for Designing Alternative Energy Systems in Consumer Products', Bas Flipsen et al. (2004) highlight the challenges faced by the designer and design engineer engaged in new product development. They suggest that the design engineer/ product designer needs data or information while ideating and generating conceptual solutions. Technical data such as specific properties of alternative power sources like fuel cells, solar cells, and to a lesser extent – human power. Some of these are made available widely in published literature. However, these publications are mainly based on 'technology-push' instead of 'consumer demand', making them difficult to comprehend and assist in design decision-making.

Their study highlights the shortcoming in utilizing such information because:

- The available data is very detailed and unsuitable to use in the early phases of the design process.
- Information about PV systems is available in handbooks, mainly for larger standalone systems, or in the form of tech sheets from the OEMs.
- The tech sheets cannot be used during the concept and system-level design phases and should be translated to more usable parameters.
- Data made available by experts in the field is often of such detail that it is hardly possible to use without much interpretation.

Considering the diverse knowledge domains that it draws from, their study reveals that the data about solar PV technology presented and made available is very scientific, making it ineffective for product designers to use during concept generation. Their study proposes an interface to communicate technical data ('united in knowledge base') accessible and valuable for the Design Engineer (Flipsen, Jansen, Bremer, & Veefkind, 2004).

It can be argued that these findings could be one of the reasons that deter industrial designers the undertaking PIPV product development. This shortcoming highlights a significant gap that this research must help to address.

It is proposed to examine and address this need in the later chapter/s that can outline a model and develop a user-friendly interface that will help the design engineers/designers translate and communicate technical data in an accessible and valuable form.

Figure 2.11 summarizes graphically the need for developing the interface to communicate technical data that presents accessible and valuable parameters for design engineers/product designers.

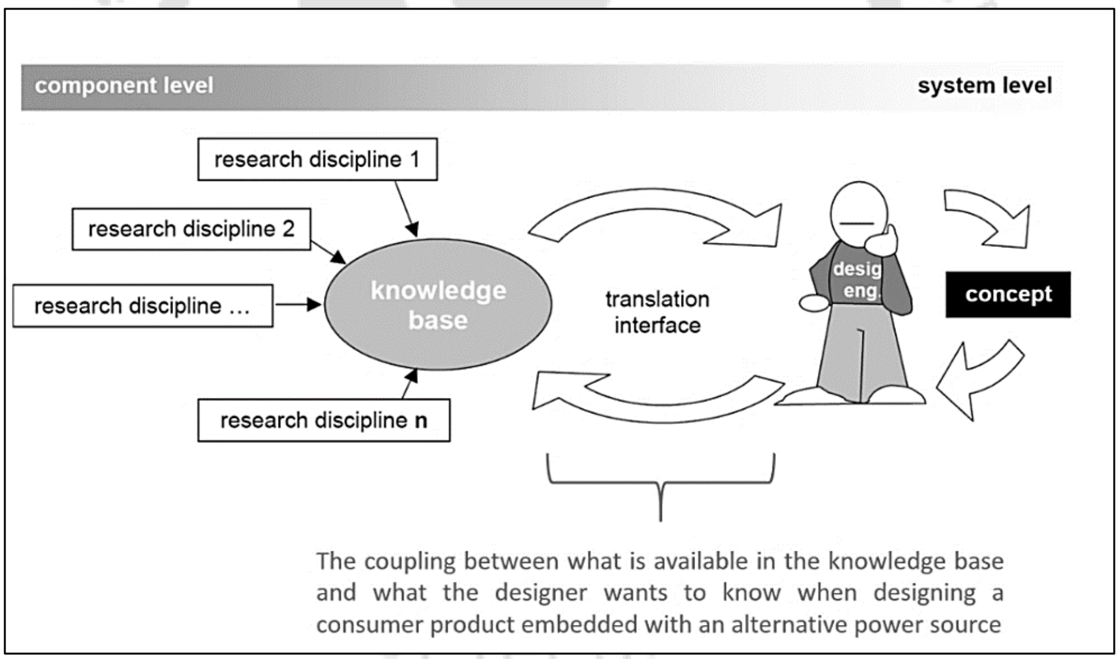


Figure 2.11 An interface to communicate technical data to accessible and valuable parameters for Design Engineers

Such an interface will also be very useful for the product designer working on a human-centred approach to product development.

Other studies have similarly attempted to understand the problems faced by designers while dealing with new technologies like solar photovoltaics. Menno Veefkind et al. (2004), in their study, 'Industrial Design and PV-Power, Challenges and barriers', highlight the role of industrial designers in developing new solar-powered consumer and personal products. It goes into the specific problems industrial designers experience when designing solar-powered products. Their study aims to identify problems in terms of methodology, knowledge, and tools that industrial designers face when developing PV- based, solar-powered products. Similarly, the assessment of product ideas based on energy balance was experienced as very difficult by the industrial designer. It highlights the need to make energy balance understandable to the product designers.

The study by Ana Mestre and Jan Carel Diehl (2003), 'Design guidelines for integrating renewable energy into consumer products', identifies the need for guidelines when integrating renewable energies like human power, fuel cells, and solar PV power in consumer products. As per this paper, they see applying these new energy technologies to product design moving from an experimental phase toward a discipline in Industrial Design. Hoed (2003), on the other hand, suggests that structural knowledge regarding identifying and integrating renewable energy technologies into products is needed for both technology developers and industrial designers. This study introduces a checklist for the designers to select renewable energy sources according to the problem and context. Their analysis shows that energy technologies are also a matter for the designer to make decisions. Decisions have their consequences, and consequences touch the future and quality of life for the next generations.

Reinders, A. H., Diehl, J. C., & Brezet (2013), in their book 'The Power of Design: Product innovation in sustainable energy technologies', offers an introduction and practical guide to product innovation, integrating key topics necessary for designing sustainable and energy-efficient products using sustainable energy technologies. Outlined in this book are various innovation methods from the perspective of sustainable energy technologies with case studies about product designs from rural and urban scenarios. These methods and case examples offer directions for a context-specific consideration in adapting to the Indian rural context.

Two other studies, viz. 'Options for photovoltaic solar energy systems in portable products' (Reinders, 2002) and 'Designing PV powered LED products-Integration of PV Technology in innovative products' (Reinders, de Boer, and Winter, 2009) focus specifically on the development of PIPV products. The former highlights the increasing opportunities for developing PIPV products in high-power applications due to their falling costs and economic viability, while the latter emphasizes the market opportunities for developing novel business models through innovations in products and services using LEDs and PIPV technologies.

2.5 Solar PV energy and Sandbox culture of Product Development

N.K. Sharma et al. (2011), in their report 'Solar Energy in India: Strategies, policies, perspective and future potential', summarize the potential and progress of India in Solar PV power generation. According to them, Solar energy is important for India since we enjoy nearly 250-300 sunny days in a year, with an average intensity of solar radiation of 200 MW/Km square (megawatt per kilometre square). However, this resource is currently underutilized. It has the potential to offer an improved power supply (especially in remote areas) and increase the security of India's energy supply (Sharma, Tiwari, & Sood, 2012). They suggest adopting a long-term perspective for developing innovative products using new materials, processes, and applications based on PV technologies. Their study conclusively indicates that photovoltaic power systems will have a significant share in the electricity of the future, not only in India but also across the world.

Considering the opportunities that this renewable energy source offers, it becomes pertinent to inquire about the shortcoming in the acceptance of PV-based products and systems. What are the end users' perceived apprehensions about accepting PV-based products as an alternative to regular electrical power-based products? Are they commercially viable and attractive as an alternative? Are they sustainable as a business proposition? Are there case examples of PV-based products/ product systems that can be examined?

They investigated the householder's attitude towards characteristics of solar systems; Adam Faiers and Charles Neame (2006) attempt to understand consumer attitude towards domestic solar power systems, using householders in central England. Their study identifies some of the barriers to adoption directed toward informing future marketing activity. They make the following four observations:

- That the innovation must possess attributes perceived as attractive to adopters.
- In the awareness stage about the invention, the adopter is concerned with innovation characteristics, particularly its advantages over another product (Faiers & Neame, 2006).
- Suppliers and manufacturers should work closely with the early adopters to develop the operational, economic, and aesthetic aspects of products.
- Suppliers should better understand customers' perceptions to create products that meet their needs.

Figure 2.12 below shows these various aspects of solar PV product design.

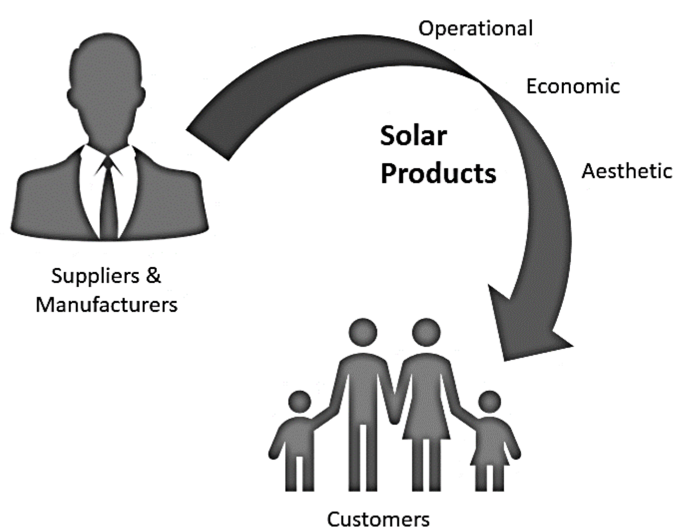


Figure 2.12 Aspects of solar PV product Design

2.5.1 PIPV-based product interventions – a review of case studies

We now study the following three case examples of PIPV products that are commercially launched to understand the underlying characteristics and features for their success/failure.

Case 1: Solar Powered Agricultural Insect Trap.

Eosolatec Company Limited, which originated in South Korea, developed a solar-powered agricultural Insect trap (Ecosolatec, 2011), including a Solar PV panel, light bulb, rechargeable battery, and fan. All these components make this PIPV product specifically for agricultural use. Figure 2.13 shows the Solar-powered (PIPV) agricultural insect trap.

Figure 2.13 Solar-powered (PIPV) Agricultural insect trap (Ecosolatec, 2011).

The product combines various components to achieve the function of an insect trap. It has a small solar panel that charges the battery and lights the bulb at night, which attracts the insects toward it, and the fan attached at the bottom sucks the insects and traps them in a sac attached to the product. This product is a creative combination of multiple components and a novel way of exploring technology resulting in a functionally effective product that integrates form and function.

Case 2: Lion lights by Richard Turere

Young inventor Richard Turere from Kenya faced the problem of lions attacking their cattle and got the idea of blinking lights to keep lions away from their village (TED, 2013). He invented solar-powered ‘lion lights,’ an elegant way to protect his family's domestic cattle from lion attacks. Figure 2.14 shows his innovation

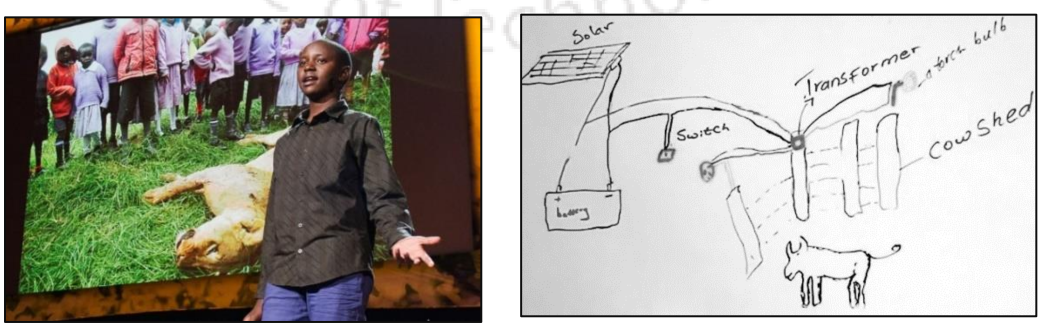


Figure 2.14 Richard Turere and his invention of lion lights (TED, 2013)

In this case, this grass-root innovator was aware of the basic technology and thought to combine multiple components to solve the particular problem. It highlights that identifying the problem is equally important in finding an appropriate design solution for it.

Case 3: Solar-Powered Trash bin.

USA-based manufacturer Big Belly developed Solar PV-powered (PIPV) trash bins with solar PV panels, IoT circuits, and sensors. The product combines solar panels, Electronic circuits, and sensors. When full, this bin sends a signal to the authority to empty it (Joshi, 2016). This concept is beneficial to managing a substantial number of bins and an efficient waste management system. This product was the outcome of the smart waste recycling and management system for smart cities. Figure 2.15 shows this PV-powered trash bin

Figure 2.15 Solar PV powered trash bin (Joshi, 2016)

These case examples suggest that by exploring technology creatively, rural problems can be solved. Such an approach of creative exploration of technology in new product development is referred to as ‘Sandbox culture’.

What is sandbox culture? In their book' Design Research through practice', Koskinen, I. et al. (2011) state sandbox culture as ‘finding problems and solving them by finding answers by exploring technology creatively through engineering imagination, not scientifically’.

Supporting their argument, they draw from the above case studies drawn from advanced design practice as its starting point, then enrich it to build a design process that can respond to practical problems. Such a process in design research methods has pushed the boundaries beyond the established approaches involving user studies. They suggest that this approach is similar to engineering in Thomas Edison's Menlo Park or the hacker culture of Silicon Valley in the 1970s. They state that a leading consulting Design firm like IDEO has drawn rich dividends over the last two decades in their professional practice that can be said to be characterized as "technology brokering": finding problems and solving them by finding answers by exploring technology creatively through engineering imagination, not scientifically.

In order to understand the creative intervention possibilities in the design and development of innovative and novel solar PV products, the sandbox culture could be adopted to trigger innovation in solar photovoltaic product design in the rural scenario by introducing a designer in the process.

2.6 Literature Synthesis Matrix

Taking a comprehensive overview of the published sources covered in the earlier section, in this chapter, we have attempted to review the relevant inter-related developments drawing from the three domains understudy, viz. Industrial Design challenges in the development of PIPV products, solar energy technologies, and opportunities in India's rural sector are the focus of this research. These are summarized in a table constituting the literature synthesis matrix presented in Appendix 1. They constitute the key conceptual findings of our literature review relevant to our study. In Figure 2.16 below, we have graphically mapped these studies on the research area diagram.

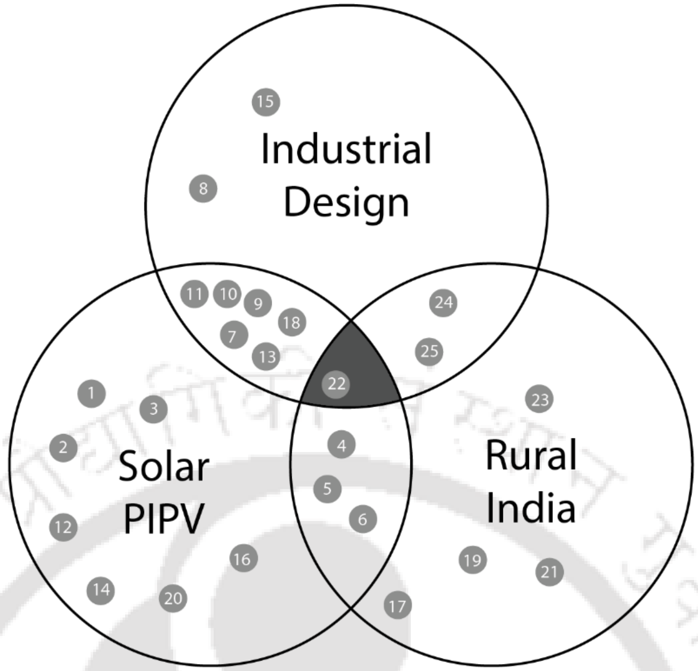


Figure 2.16 Mapping of literature synthesis matrix on intersection map of three study pillars.

As can be seen, the study has helped identify the explored areas according to the three domains considered pillars of the study. It is seen that most of the studies seem to cover either one / or two of the three aspects of our research focus, as seen in the overlapping domains. Only one study has attempted to comprehensively consider the three overlapping intersecting domains of development of PIPV technology-based product development, Industrial Design consideration, and the context of their appropriateness for meeting the context of rural needs. It clearly emerges that there is a need for a suitable design methodology that is easy to use for industrial designers engaged in developing PIPV based products/ product systems suitable for meeting the vast opportunity needs of rural users in India.

This sets the directions of inquiry for a suitable methodology for designers engaged in developing PIPV based products/ product systems focused on Indian rural user needs.

2.7 Chapter Summary

In this chapter, a literature review has been conducted on PIPV product design, solar energy for rural India, and industrial design, which has provided background information on the earlier studies in this area and set the direction for further planning of the experiments in research. The studies highlight the untapped opportunities of solar energy to meet electric power generation for rural India. It also highlights the relevance of PIPV based product systems for off-grid energy solutions for the people staying in rural and remote areas of India. As a strategic and creative problem-solving process in designing and developing PIPV products, industrial design can play a significant role. Considering this direction, it becomes necessary to conduct a detailed field-based study to identify different PIPV products for the Indian rural scenario. Studies reviewed in the literature also seem to identify and highlight the barriers to the industrial design of PIPV products. Earlier studies in product design and development elaborate on the importance of design in the product conceptualization process. Considering PIPV product design, there are requirements of data related to the problem being solved and the technology being used to achieve the product's function. This data should be made easily interpretable for designers to generate PIPV product concepts. The design concept developed through such a directed process should aim to make these products contextually viable and economical in use.

As seen in the literature synthesis matrix, most of the earlier studies focus on either one or a combination of two pillars of the present research. Our objective behind this study is to explore the area of research at the intersection of three pillars of study. From the extensive literature search, it is observed that there are very few attempts to explore the integrated and overlapping considering the intersection of Industrial design, PIPV products, and rural scenarios together. Also, most research studies cater to industrial mass production and business-oriented approach. This research study will contribute to acting at the intersection of the three pillars and add to the knowledge by developing a contextually appropriate methodology for designing and developing PIPV products/ product systems.

CHAPTER 3

Research Design

Chapter three of the thesis outlines the design and methodology of the research. It defines the flow and direction of research to achieve the aims and objectives stated in section 1.8 of chapter one. Research is organised by outlining various studies, and specific methods are applied to get a detailed analysis. In this chapter, this is described comprehensively.

3.1 Introduction

Following the six-layered Onion Model in Research Design (Saunders, Lewis, & Thornhill, 2007), this study adopts a Pragmatist's outlook to the research study. The research focuses on the identified problem and intends to contribute practical results that shape future practice. For the desired expected outcome, the research methods recommended are qualitative or mixed methods of enquiry (Iovino & Tsitsianis, 2020) (Sahay, 2016)

Considering the complexity of the different overlapping parameters of technology, people and processes involved in the product development process, there would be different ways of undertaking the research and "that no single point of view can give the entire picture and that there may be multiple realities" Saunders et al. (2007). The mode of data collection will involve a multi-method involving more than one strategy for data collection and analysis that will address the research questions mentioned earlier. The different experiments will be conducted within the overarching time constraints of the research duration.

Therefore, a qualitative methodology is ideally suited for the study in which the approach adopted is one of abduction.

3.2 Research Framework

In the summary of the previous chapter, we identified from the Literature synthesis matrix that this research aims to develop a context-appropriate methodology for industrial design in the development of PIPV products that meet the needs of rural communities in rural India.

As highlighted through the literature review, it is premised on the assumption that due to limited or lack of access to the electricity grid, solar PV is essential and appropriate to fulfil the energy needs in geographically remote and rural locations in India that do not easily have access to the grid-based electric power supply.

Figure 3.1 shows the three fundamental aspects of our study: the research's context, focus, and intervention area. The study is framed around the above three intersecting aspects.

Table 3.1 Context, focus and intervention area of research

Research	Context	Rural India	The context of research is the scenario of Rural India as the life of people associated with the lack of basic electricity needs, which can be fulfilled by Intervention in Solar Photovoltaic Energy
	Focus	PIPV Products	Research is focused on PIPV products that work on solar PV energy, which is produced by Solar PV panels integrated into the product itself. It makes them standalone, grid-independent and idle for use in the scenario of remote and rural places where there is no grid or intermittent electric supply.
	Intervention Area	Industrial Design	Industrial Design is a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences. Industrial Design intervention of PIPV products will lead to innovative solutions to improve the quality of life of people staying in rural and remote places of India.

Further, it also emerged that the methodology followed must be easy to comprehend and use by designers engaged in PV based product development for rural needs.

Considering the application-focused outcomes that are needed, it is only appropriate that we select an appropriate methodology that is pragmatic in its intention to meet the aim and objectives of our research. The research process and its various stages are schematically shown in Figure 3.1 below.

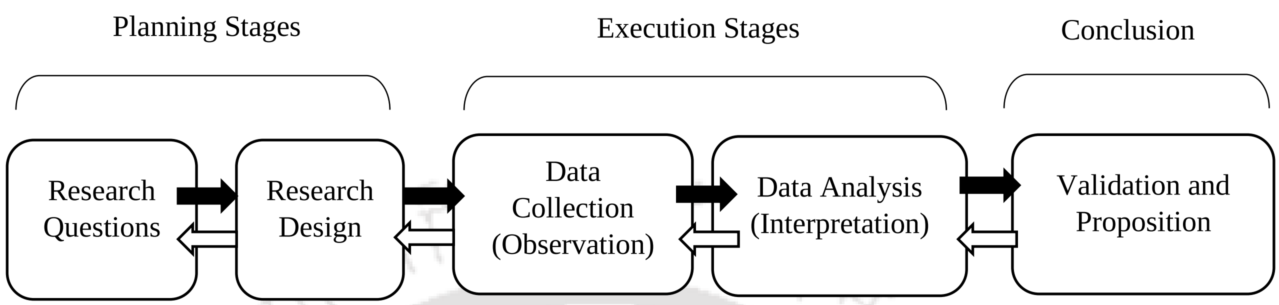


Figure 3.1 The research process.

The research design is framed around the research questions and the experimental execution. The process consists of the following five stages:

Stage 1: Defining the research questions

Stage 2: Planning the Design research

Stage 3: Conducting Experimental Studies using multi-methods

Stage 4: Data Analysis (Interpretation and Insights)

Stage 5: Validation and proposition with conclusions

The solid arrows in the process depict the sequence of research stages and activities. However, considering an exploratory approach of the study, the light arrows at the bottom indicated the iterative nature of the research.

3.3 The Research Questions and Planning of the Research Approach

The research design is framed around the formulated research questions, and the experiments for the study are divided correspondingly around each research enquiry. Viz.

<u>Enquiry 1.</u> What are the potential areas of intervention for PIPV products in rural India, and what are the needs of users that designers should consider?

> ***Research Question 1:*** What are the crucial electricity-dependent needs of people which can be addressed through PIPV product interventions by designers?
>
> ***Research Question 2:*** What are the available PIPV interventions in the market, and what user needs they are addressing?

<u>Enquiry 2.</u> What are the challenges in developing PIPV products; the type of support and input information required for Industrial designers in each phase of PIPV product development?

> ***Research Question 3:*** What factors affect the industrial design process of PIPV products, and is there any support required for it?
>
> ***Research Question 4:*** How does the PIPV product transform from the ideation phase to the realization phase with the input information and support in each phase of development?
>
> ***Research Question 5:*** What evaluation model can be adopted to evaluate the PIPV products in a rural context?

<u>Enquiry 3.</u> What should be the possible approach to proceed with the Industrial design and development of PIPV products in a rural context?

3.4 Planning the Research Experiments

The experimental research is designed in various sub-studies that address the research questions. Figure 3.2 shows the overview and flow of research schematically in the context of the corresponding Design phase of the Product Development Process

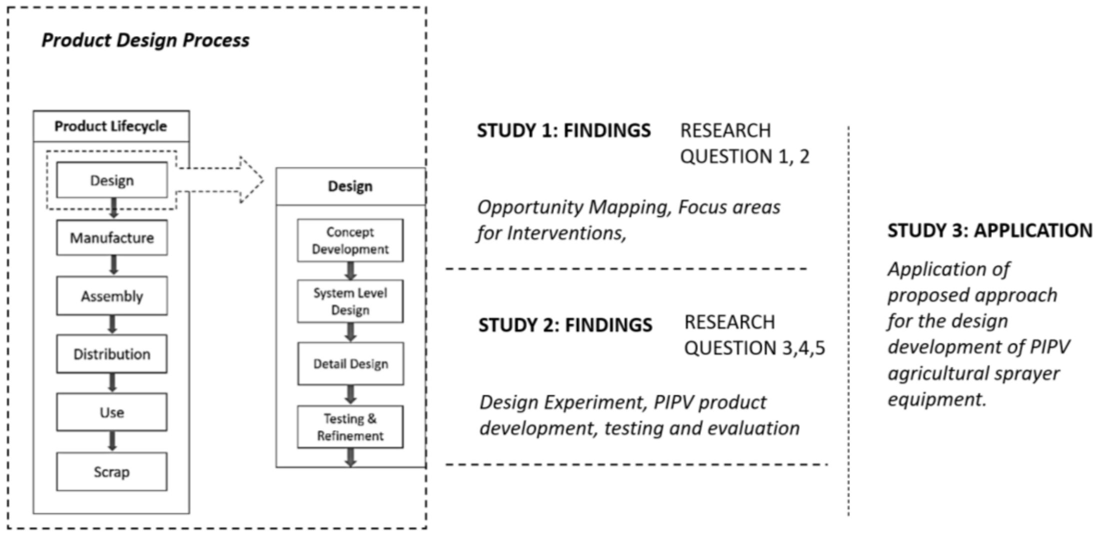


Figure 3.2 Study1, Study2 and Study 3 associated with various stages of the product design process

The Experiments for the Design Phases

The schematic includes the phases of:

- Identification of Opportunities for Design Intervention
- Concept Development;
- System-Level Design;
- Detail Design
- and Testing and Refinement.

3.4.1 Opportunity Mapping

The planned studies highlight the associated research questions that the experiment aims to answer.

Experimental Study 1:

Aim: Findings focused on identifying Opportunity Mapping to identify the opportunities for PIPV intervention leading to Concept Development.

It will answer Research Questions 1 and Research Question2.

Research Method: Field Visits; In-person Interviews; Direct Observations

Process Details: The experiment consists of two parts.

Part 1: Field visits will be undertaken to three villages in Maharashtra and Two villages in Meghalaya.

Two contrasting rural environments with varying climatic conditions; the familiarity with the local language, Time constraints and Cost constraints; and Interpersonal contact with the local community formed the basis of the identification and selection of the villages.

Direct Observations of life in the rural village, including daily chores, agricultural activities, facilities and infrastructure available and the range of different products put to regular use, would be observed and subsequently mapped, categorized and analyzed to identify the opportunity gaps.

Part 2: the study identifies commercially available PIPV products in the market and analyses them against the end-user needs these products met.

A number of grass-root innovations have been identified under the National Innovation Foundation network in India. These would be identified for analysis.

The approach would include

- Identification of different PIPV products from online and offline platforms,
- Identification of grassroot innovations from various government portals like the National Innovation Foundation and GYTI Techpedia.

Analysis and insights to identify the potential areas of intervention are undertaken from the above data by mapping and categorising the range of products in the market and those recorded under grass-root innovation based on Maslow's hierarchy of needs. A Likert scale analysis method is used to interpret the rating received from various stakeholders associated with the study.

The opportunity gaps for design intervention will be identified based on this detailed analysis, covering the design stage 'Need and opportunity gap identification.'

3.4.2 PIPV Product Development

Experimental Study 2:

Aim: The experiments aim to study the Product Development Process. The experiments will study the following aspects of the different Design Phases, viz. Design Specification; Detail Design, Testing, and Design Refinement are involved in the overall approach for PIPV product development. They will seek to answer Research Questions 3, 4 and 5.

Approach: Exploratory Design workshop will be conducted with Design professionals for the Design Ideation and Concept Development phase of PIPV based products. The objective is to study and analyze the process they undergo, their understanding of the rural needs and the technical challenges they face in ideation and concept development.

The analysis would give insights into formulating a PIPV domain-specific process for product development for rural needs. It will help to identify if specific design assisting tools are required to be developed to help young professionals and design students in the product development of PIPV products.

Two specific case examples will be developed in the domain of agricultural/rural needs, including product prototyping, to gain insights into the challenges in carrying concept ideas to their product realization stage. These will be taken for field testing to evaluate the process efficacy and real-world feedback from the rural stakeholders who form the targeted end-user segment. The insights drawn will help assess the efficacy of the design process adapted to the product development process.

3.4.3 Application of Proposed Approach for Design of PIPV products

Study 3:

Considering the different opportunities for PIPV product/system intervention of different applications for PIPV products, a specific case of product development for agricultural needs will be undertaken as a case using the proposed process.

The prototype developed will be field-tested following specific modes of the evaluation process in the Product Development of PIPV products. This will help assess the efficacy of the proposed design process for PIPV development in the rural context.

3.5 Research Progression Diagram

The research progression diagram shown in figure 3.3 shows the flow of research with research activities and methods with respective outcomes. From the proposed research plan for the experimental studies, four significant findings are the anticipated outcomes of various research activities associated with the studies involved in this research. It includes the development of two PIPV products that will be designed and developed to get the inputs on the design process and user feedback through field testing. The proposed process will define the approach and its evaluation in the user environment. The research progression diagram shows the direction and flow of research. The detailed process of the research activities related to findings 1,2, and 3 will be described in chapter four, and the studies related to findings 4 will be outlined in chapter five of the thesis, which is to follow. Chapter six will set the platform for describing the application of the proposed defined approach for the industrial design of PIPV products. The research study will be summarized in the concluding chapter, outlining the possible research approach and guidelines for designing PIPV products in rural India.

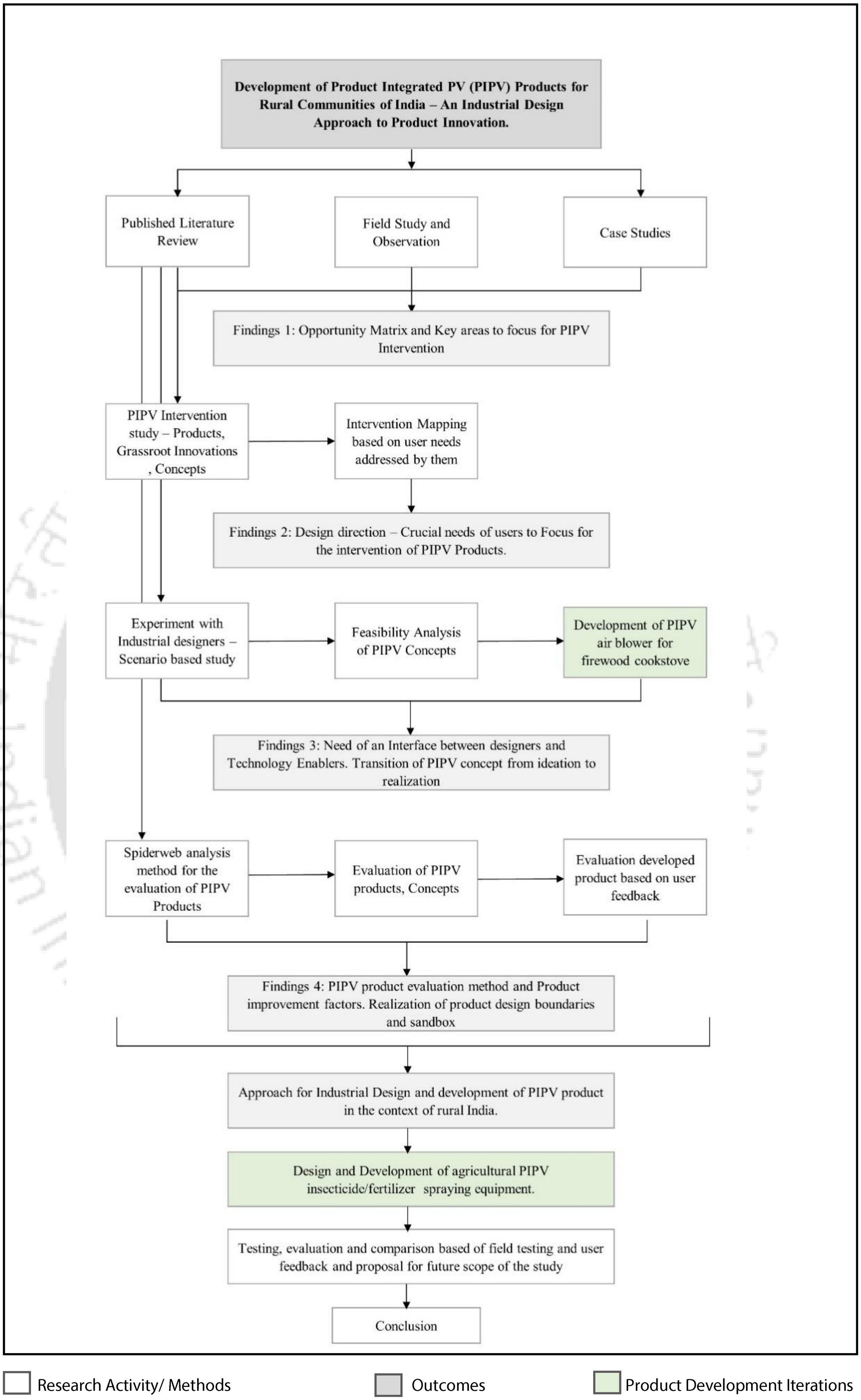


Figure 3.3 research progression diagram

3.6 Chapter Summary

Research design is a crucial part of any research study. The design and framing of research streamline the various activities and investigations. Various methods used to conduct research studies are described in this chapter. The studies are defined to contribute to different phases of the design process through their outcomes. The research progression diagram is framed to comprehensively envision the overall flow and direction of the research study. This chapter establishes the research focus and the methods and models adopted to conduct various studies.

CHAPTER 4

Design For Rural India: Opportunity Mapping for Industrial Design Interventions of PIPV Products, Design and Development of PIPV.

Following the multiple design stages adopted from the product design process defined by K. Ulrich (Ulrich, 2003) and W. Hsu et al.(Hsu & Woon, 1998), the experimental research studies undertaken and covered in this chapter. To identify the opportunity gap for intervention in developing PIPV products in the rural context. Field studies, Direct Observations and Review of Existing products are the methods adopted for analysis.

This chapter describes the insights gathered from the case studies and field visits to villages of Maharashtra and Meghalaya states of India. From a detailed analysis of the data collected, we map the opportunity domains identified for intervention for designers working in the development of PIPV products in a rural context.

4.1 Introduction

As outlined in the research plan in the previous chapter, in this chapter, we describe the insights gathered from:

- A review of three case studies; and
- Field studies undertaken by the researcher in selected villages of Maharashtra and Meghalaya states of India. These two different states are located geographically in India's western and eastern regions and experience contrasting climatic conditions. The villages visited in these locations were easily accessible for visits and study for this author.

This preliminary field study identifies the opportunities for real-world design intervention for developing PIPV products that are contextually relevant to the rural needs of the region. It sets the direction for outlining the Design process for PIPV based product development, meeting the set aim of this research.

This chapter forms a major part of the experimental studies contributing to analyzing and developing the design process in the PIPV product development for a rural context. The chapter is divided into four sections covering the studies and insights gathered on opportunity identification, PIPV product design intervention, challenges in the design process, and testing evaluation of PIPV products with users. Below are the four sections and the respective studies covered under them

Section 1: Three Case studies in PIPV product interventions in rural India, Preliminary field studies, direct observations and user interviews, and an opportunity matrix for PIPV interventions are discussed.

Section 2: Mapping PIPV product interventions for need identification (commercialized PIPV products, grassroot innovations and Design interventions by designers) are undertaken and reviewed.

Section 3: Assessment of PIPV products is undertaken in this section. It adopts a suitable model to evaluate and assess PIPV products based on user feedback.

Section 4: A scenario-based design experiment is conducted to identify the challenges in the design process of PIPV products in a rural context. The design workshop and its outcome in the form of PIPV product concepts generated are discussed.

These sections are elaborated on in the sections that follow.

SECTION 1

4.2 Three Case Studies in PIPV Product Intervention in Rural India – A Review

The following three PIPV related interventions were identified as case studies for a detailed study. They met the overlapping domains of this research study and added different perspectives and challenges faced in this research domain. The study includes:

- Development of Solar PV Light design for Rural India by Panasonic (Panasonic Corporation, 2015)
- Intervention initiated by the NGO Anandyatri in facilitating the distribution of PIPV lighting undertaken under their Project Suryodaya (Suryoday, 2014); and
- Product innovations in PIPV products for rural needs in India by Flexitron Ltd. Bengaluru, an innovation-centric enterprise acting for the rural population (R.S.Hiremath, 2021)

Details of these case studies are described in the following sub-sections.

4.2.1 Case 1: Solar PV Light design for Rural India

The market potential for Solar PV lighting can be assessed by the fact that a sizable population of over 75 million or 33% of households in India are off-grid and are typically overly dependent on burning a non-healthy and harmful resource like kerosene for lighting kerosene lamps (Gretebeck, 2017). Driven by the potential to offer a more sustainable alternative to this significant large rural market, Panasonic India designed and developed a Solar PV light for Rural India. A pilot study undertaken by the firm in the two large states of Jharkhand and Uttar Pradesh indicated a severe lack of access to electricity in rural and remote areas. Their analysis highlighted the particular needs of rural people and identified specific issues related to lighting. The study indicated that women in these villages were unable to earn any noteworthy income during the day as they were preoccupied all day completing their household work before dusk. Rural school and college-going students experience difficulty studying using conventional kerosene lamps and candles at night. These sources were neither cost-effective in the long run and rather affected personal health. Agricultural activities like watering crops during the night required lights. The study also noted a social imbalance in the community due to the absence of appropriate lighting devices (Corporation, 2013). Drawing from these observations, they focused on cost and quality as the thrust of product development following a user-centred approach. The product is conceptualized by integrating various functions, including mobile charging. To increase the number of working hours, the efficiency of the product was of high priority. Figure 4.1 shows this solar PV light design by Panasonic

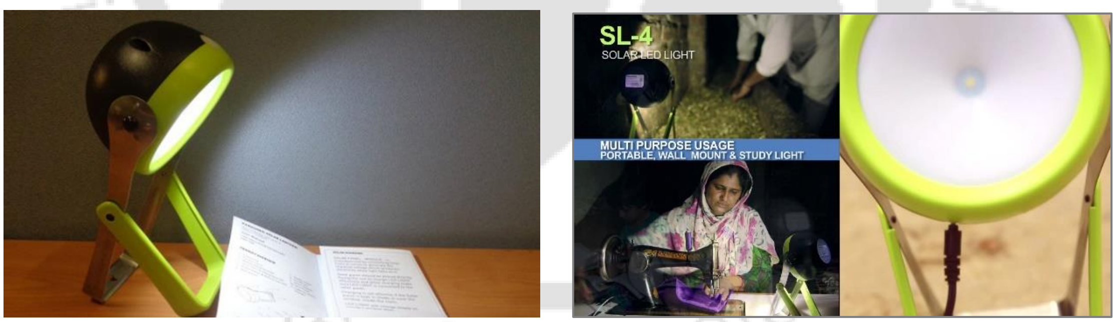


Figure 4.1 Solar PV Light design by Panasonic (Panasonic Corporation, 2015)

A major issue identified in this study indicated that partnering with NGOs in the rural sector is necessary for successful market penetration and must be factored into developing any rural products. Based on insights drawn from this study, Panasonic developed different solar-powered lights for the rural population.

Figure 4.2 Second Variant of Solar PV Light design by Panasonic

Figure 4.2 shows the variant of indoor light developed by Panasonic for final distribution to people staying in rural areas under the ‘Hundred thousand solar lighting project’ (Corporation, 2013). Figure 4.3 summarizes the identified issues, and the development direction followed for the design and development of solar PV light.

Identified issues	*women must finish house chores while it is light outside*	*Difficulties in studying for kids during night*	*Some of the agricultural activities are dependent on light*	*There is Social imbalance in absence of light*
Development direction	*Focus on cost and quality with user centered approach*	*Multiple functions in single product (Inclusion of mobile charger)*	*Efficient product with maximum possible hours of usage*	*Partnering with NGOs to penetrate to rural and remote areas*

Figure 4.3 identified issues and development direction.

4.2.2 Case 2: Project Suryodaya by an NGO Anandyatri

Anandyatri is an NGO working in rural and remote areas of Maharashtra state. This NGO distributes solar-powered lanterns to rural communities by networking with well-wishing donors across the country. Information was first gathered from their newsletters and social media platforms (Suryoday, 2014) to understand their initiative to distribute Solar PV lights to people staying in rural and remote areas. Subsequently, an interview was conducted with their representative volunteer Mr Prasad Shinde. Mr Shinde informed this researcher that their team periodically organizes donation drives for Solar lanterns that they receive from various donors across the country. Donors contribute PIPV products to the NGO Anandyatri through online marketing platforms like Amazon and Flipkart. After receiving a sufficient number of products, volunteers conduct donation drives to distribute those products to needy families in these rural and remote areas as per the number of units received from each donor.

Figure 4.4 shows the donation drives under project 'Suryodaya' by Anandyatri.

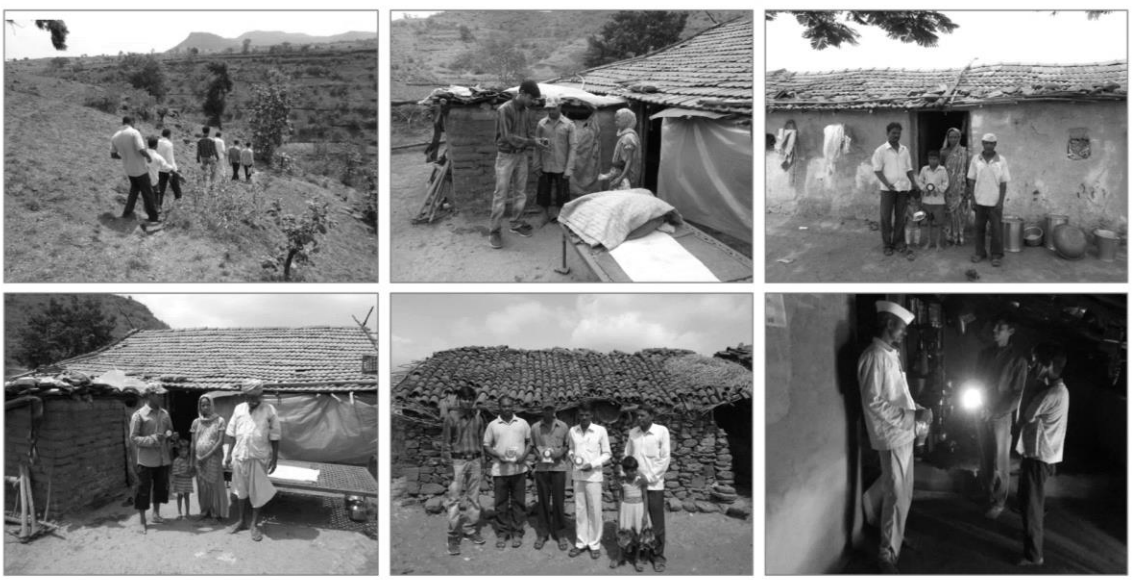


Figure 4.4 Project Suryodaya team on solar lantern donation drive.

They work on a unique model with a specific approach for the distribution of solar products, which is graphically outlined below in figure 4.5

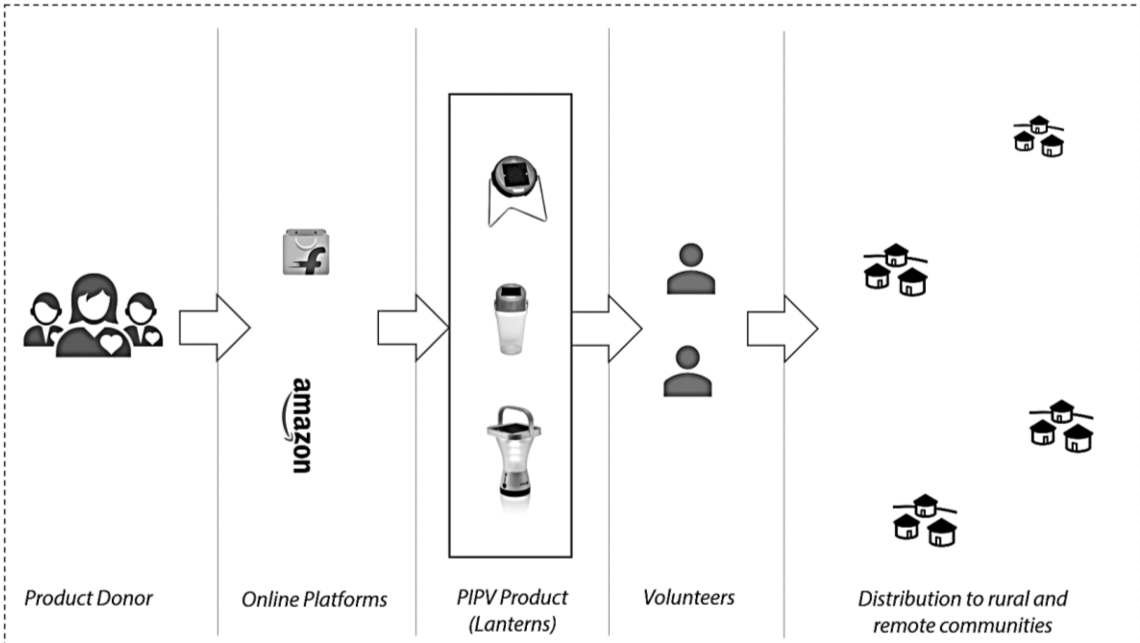


Figure 4.5 Approach for Solar products distribution

It must be noted that this successful model offers the potential to extend consideration of other related PIPV based products apart from lighting. A study of various other electricity-dependent activities in such a rural setting needs to be identified to successfully address other needs of the rural community. It requires a serious attempt to identify and meet these rural needs through multiple product solutions. It is a research gap that this research will address in the subsequent sections to follow.

4.2.3 Case 3: Flexitron- An innovation enterprise

Flexitron Pvt. Ltd., Bengaluru, is an innovation-led enterprise established in 1989 by its Founder Director, Mr R. S. Hiremath. This firm is actively working on solar PV innovations for rural India. Mr R. S. Hiremath, in an interview with this researcher held in Bangalore in November 2017, highlighted the need and importance of innovations for rural India. According to him, the tasks and struggles of a rural person remain potentially unattended with little change. It offers a high potential for context-appropriate interventions through product development and innovation by understanding the lifestyle of rural people and developing economically and functionally good products to make their lives comfortable. This conviction has been the driving motivation for Mr Hiremath personally is putting his lifetime effort and ambition to deliver the best products using technology and innovation to reach the poor, the oppressed, and the less fortunate. FLEXITRON produces various PIPV based products in batches as per market requirements and demand. Some of their inventions are shown in Figure 4.6 below

Figure 4.6 from the left; solar-powered community-based mobile charger, Solar PV powered hearing device, Solar-powered rice husk remover, extreme right; solar-powered battery charger device.

Identifying product intervention and ‘technology push’ in meeting context-specific rural needs drive product innovation at Flexitron. The product range is technically mature in meeting ‘structure and function’ needs. Mr Hiremath made an observation that a trained industrial designer's inputs could significantly contribute to enhancing usability features for product success.

4.2.4 Insights from case studies

Below are summarized the insights gathered from these three different case studies.

- The cost and Quality of products are significant considerations in the rural scenario.
- There is a demand for multipurpose and multi-functional products due to various electricity-dependent activities.
- It is challenging to penetrate rural markets. The contributions and engagements of NGOs and similar organizations that are active in this scenario can be considered

partners and critical stakeholders in creating a positive impact on wellbeing and successful intervention.

- Community-based products and innovations are suitable for such rural scenarios for communities since these marginalized, and economically weak groups of users may not have individual buying capacity.

Based on the insights gathered from the case studies, field visits were undertaken to gather information and first-hand experience of the lifestyles of rural communities in select village locations in India. This is described in the next section of the chapter.

4.3 Preliminary Field Studies, Direct Observations and User Interviews

As the first step towards need identification that is culturally appropriate for a rural setting, the researcher undertook field studies in select villages, including Deothan, Sarole Pathar and Shendi Village of Ahmendnagar district of Maharashtra state and Kynmynsaw, Kynbah villages of Mawsynram district of Meghalaya state. The aim was to collect first-hand data from direct observations and in-person interviews with the local community in these villages. Enquiries were centred around the community's daily activities, social aspirations and associated issues. Interpretation of the data collected from Direct observation studies in the field aimed to gain holistic insights from the participant's perspective of the ground reality, understand people's perceptions in their living contexts and examine electric power-dependent needs. Detail exploration focused explicitly on agriculture and household activities that were undertaken during the field visit to help empathize with the people associated with those activities. Figure 4.7 shows the various methods adopted for data collection in the field.

Interviewing | **Observing** | **Exploring**

Interview Protocol is used to interview people about their daily activities, social aspirations and associated issues. We tried to understand their activities which are electricity dependent and what are the associated constraints.

Being the best possible way, we observed people doing their various activities. We tried to understand why and how they do these activities. Observations are recorded to interpret the results for further study.

Detail exploration is done in few agriculture and household activities. This helped us to empathize with the people associated with those activities.

Figure 4.7 Methods adopted for data collection in the field.

Through discussions and interactions with the rural villagers, observations of electricity-dependent activities could identify and map product intervention possibilities by categorizing them into various activity domains.

4.3.1 Field Studies to Villages in Maharashtra

The following three villages, viz. Deothan, Sarole Pathar and Shendi village of Ahmednagar district, Maharashtra state, were selected for the field study considering familiarity with the local Marathi language and personal contacts of people in these villages. The purpose of the field visits is to gain first-hand experience of the everyday work-life of the local villagers in a rural setting and to study and make direct observation of the actual scenario of the use of products and services that address and meet their everyday needs.

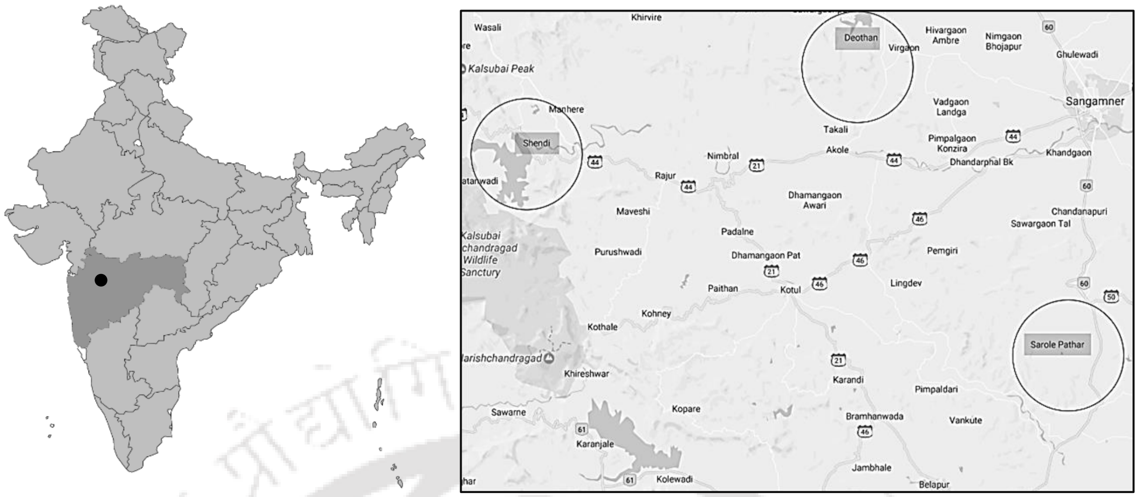


Figure 4.8 Location of Shendi, Sarole pathar and Deothan villages on the map

Visit to Shendi Village, Maharashtra

It is observed that most people living in Shendi village are involved in agricultural activities and are dependent on water from a nearby water stream. Most farmers have small segments of land where they grow paddy from the water source nearby. People engage in works like road construction during the year's non-harvesting time. They do not have farming tools like tractors and harvesters and mostly depend on conventional farming techniques. Most houses we observed managed everyday household activities in the absence of electricity. Figure 4.9. show images of village activities captured during a field visit to Shendi village.

Figure 4.9 Top Left- People engaged in road construction work during the spare time of year, Top right- Small segments of land are used as paddy fields, Bottom left- Typical village house in Maharashtra. Bottom right- Conventional farming techniques.

Most villagers in Shendi village use firewood for cooking as it is an economical and readily available source. Most of them have to do the cooking outdoors as it causes the problem of smoke accumulation inside the house due to lack of ventilation. The village market in Shendi is crowded, and the available electric supply is limited to the nearby area. Remotely located houses on the foothills and some distance from the village centre do not have electricity connections. Local transportation to the nearby town is hampered by infrequent public transport buses. People often travel in overcrowded vehicles that carry passengers over the seating capacity, as shown in figure 4.10.


Figure 4.10 Top left: overcapacity public transport at shendi village. Top right: discussion with villagers and farmers at shendi village.

Field Visit to Deothan Village

At Deothan village, we observed that most villagers are dependent on agricultural and allied activities. They do various activities through conventional farming techniques. Heavy machinery and equipment are used on a shared rental basis by the local community. Zilla Parishad schools are located in villages where children pursue their pre-primary, primary and secondary education. School activities are also hampered due to electricity-dependent issues. Lack of basic facilities of lighting and fans are prominently witnessed. Activities of a night school run for people - who cannot attend it during the daytime due to farm work - suffer due to poor electricity supply.

Figure 4.11 Conversation with villagers at Deothan village

During our conversation with community members in the village, they expressed the view that for these community initiatives' success and effective outcomes, there is a need for a reliable alternative source of electric supply for lighting, water purification, and extending services with digital learning tools for the community.

Figure 4.12 shows observations at Deothan village, located near Deothan dam on Adhala river in the Ahmednagar district of Maharashtra state. The photo documents clearly indicate that conventional farming techniques with machines and tools are used for agriculture, water and pumping needs in the fields.

Figure 4.12 Top Left- Famers using bullock plough for land preparation, Bottom left- Local water reservoirs, Top right – tractor manoeuvring through farmland, Bottom right- land preparation in progress.

Field Visit to Sarole Pathar Village

At Sarole Pathar village, the researcher visited a farmer who had installed a solar PV powered solar pump for his farm to gather information about the farmer's experiences after installing this PV system. In the interview, the farmer stated that frequent power cuts and the excessively high electricity charges, on the one hand, and the attractive government subsidy on the PV powered solar pump was the motivation behind his decision to install the PIPV based pumping system. For this PV operated 5 HP pump, the overall investment cost for the complete system was INR Five lacs. Of this total cost, he invested INR One lac and the balance of INR Four lacs he received in subsidies and grants from the scheme under the concerned government department. This scenario shows the high cost of the solar PV system and the need for considerable economic support from the government or external organizations to make the system affordable for farmers. The system comprises installing nearly forty solar panels to generate the required electricity to power the water pump, making the system very bulky. Figure 4.13 shows the actual size of the system installed near the water well of the farmer.

Figure 4.13 Top left -Solar PV powered water pumping system in Sarole Pathar Village. Top right- Discussion with the farmer (owner of the system) to get the system's information. Bottom left-system with water well. Bottom right - system specifications.

After discussing with the farmer, we found that he was pleased with the system and its performance. The pumping system was very efficient and without any maintenance and operating costs. Every villager wanted to get it, but they could not afford it because of the high capital investment.

The field visit to Sarole Pathar village and observation of this system helped identify the primary requirement of electricity-dependent water pumping for agriculture as one among the critical agricultural rural activities.

4.3.2 Field studies on Villages Kynmynsaw and Kynbah villages of Mawsynram District in Meghalaya

Meghalaya state is located in the Northeast region of India. It is a hilly terrain, with most populations belonging to various tribes. The researcher visited the two villages, Kynmynsaw and Kynbah villages of Mawsynram district, located in the Khasi Hills, to understand the diversity and contrasting challenges of the rural lifestyle. In contrast to the field visit to rural villages undertaken in the state of Maharashtra, Kynmynsaw and Kynbah of Mawsynram have a mountainous landscape. The reason for selecting these villages was the encouraging support promised by government officers of the concerned departments to assist in conducting the study with the local community and its proximity to Guwahati city. Considering the language barrier and the access to the remote areas and tribal communities of Meghalaya, permission and assistance from government officials were required. The officers of the commerce and Industries department of Meghalaya state assisted in this study.

The multiple activities typical of the lifestyle of the rural people of this region were studied for further analysis and to guide the identification of intervention areas. Figure 4.14 shows the various observations from this field visit.

Figure 4.14 Top Left- Fish ponds and water reservoirs; Bottom left- Firewood stoves for cooking and heating activities; top right – bamboo weaving baskets; Bottom right- Ropeway to transport goods to the upper town.

Due to the hilly terrain, farmlands are stepped on hill slopes, and the 'Jhoom' farming techniques are prevalent across Meghalaya state. Fishing and honey production is an integral part of agriculture and is commonly practised across the state. Bamboo is abundantly available as a raw material, boosting bamboo handicraft production. Bamboo handicraft skills are common among most tribes, and they are transferred from generation to generation. Firewood is economical and readily available and is often used for cooking and other fire-related activities. Healthcare facilities are minimal, and only basic requirements are met at the village level. We observed that many associated activities are electricity-dependent and primarily affected by intermittent electricity supply. Tools for bamboo processing and handcrafting, water purification and cooking aids, and lighting are some of the crucial electricity-dependent needs we could identify.

4.3.3 General Observations and Insights from field visits

The following general observations can be summarized from the field visits undertaken in the rural villages in Maharashtra and Meghalaya

About people living in the villages in Maharashtra, it is observed that most rural people centre their agriculturally based activities near the water sources available in the village. Most farmers have small farm holdings in the plains, where they grow paddy if they have a water source nearby. During the dry season, the local rural community shifts to non-agricultural activities for their livelihood. These could involve works like road construction, etc. The farmers in remote locations do not have farming machineries such as tractors and harvesters and fall back mostly on conventional bullock cart farming techniques. Across most rural houses, we observed that many household routine activities are managed without electricity.

Overall, during our field visit to villages in the two states of Maharashtra and Meghalaya, we could note that very few people use solar PV products. In our discussion with the villagers, we found that some of the PV-based products are used for specific reasons: fluctuating electricity supply, reliable solar PV technology, and free of cost operation of products. Figure 4.15 shows the products spotted during field visits.

Figure 4.15 left- Solar PV light in Sarole Pathar village of Maharashtra. Right – Use of solar PV panel for lighting and mobile charging in Kynmynsaw village of Meghalaya.

Users are excited to use Solar PV products because of the zero cost of operating them. It implies that other electricity-dependent activities can also be considered for solar PV iterations. It can be noted that there is wide climatic and cultural variation between the various geographically located Indian villages. Despite these variations, one can identify some basic and common user needs that can be met through PIPV based product and innovation interventions.

4.3.4 Opportunity matrix for Intervention domains for PIPV product development for rural needs

From the studies, three significant factors are seen to drive and influence the response of people in villages, viz. daily needs, Environmental issues and Government policies. Figure 4.16 shows those three factors.

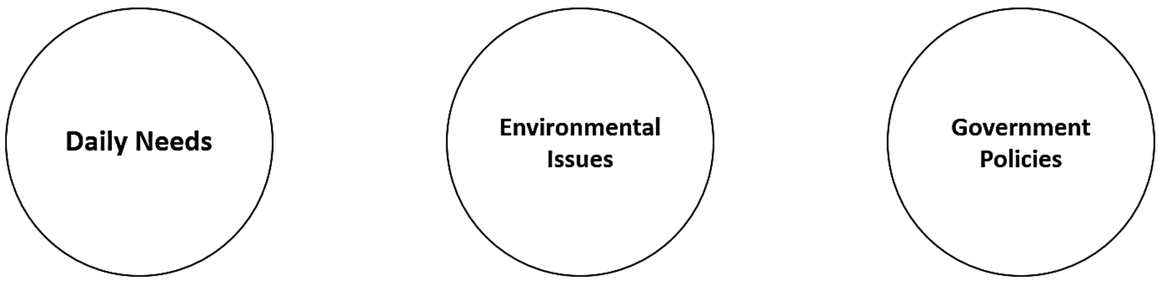


Figure 4.16 factors affecting the life of villagers

For this research, Industrial Design considerations in product development and innovation of PIPV based products that meet the user needs of rural communities are the focus of enquiry. Hence, Government policies and Environmental issues that influence and impact decisions on PIPV technologies are presently kept out of the scope of deliberation for this research. The thrust is on developing processes for PIPV product development that are contextually appropriate

Learning from the case studies and the field visit to the villages, we are able to identify four domains of the various activities anchored in rural communities. These are categorized under agricultural activities, education, healthcare and daily household activities. Figure 4.17 shows the diverse domestic daily needs and associated activities.

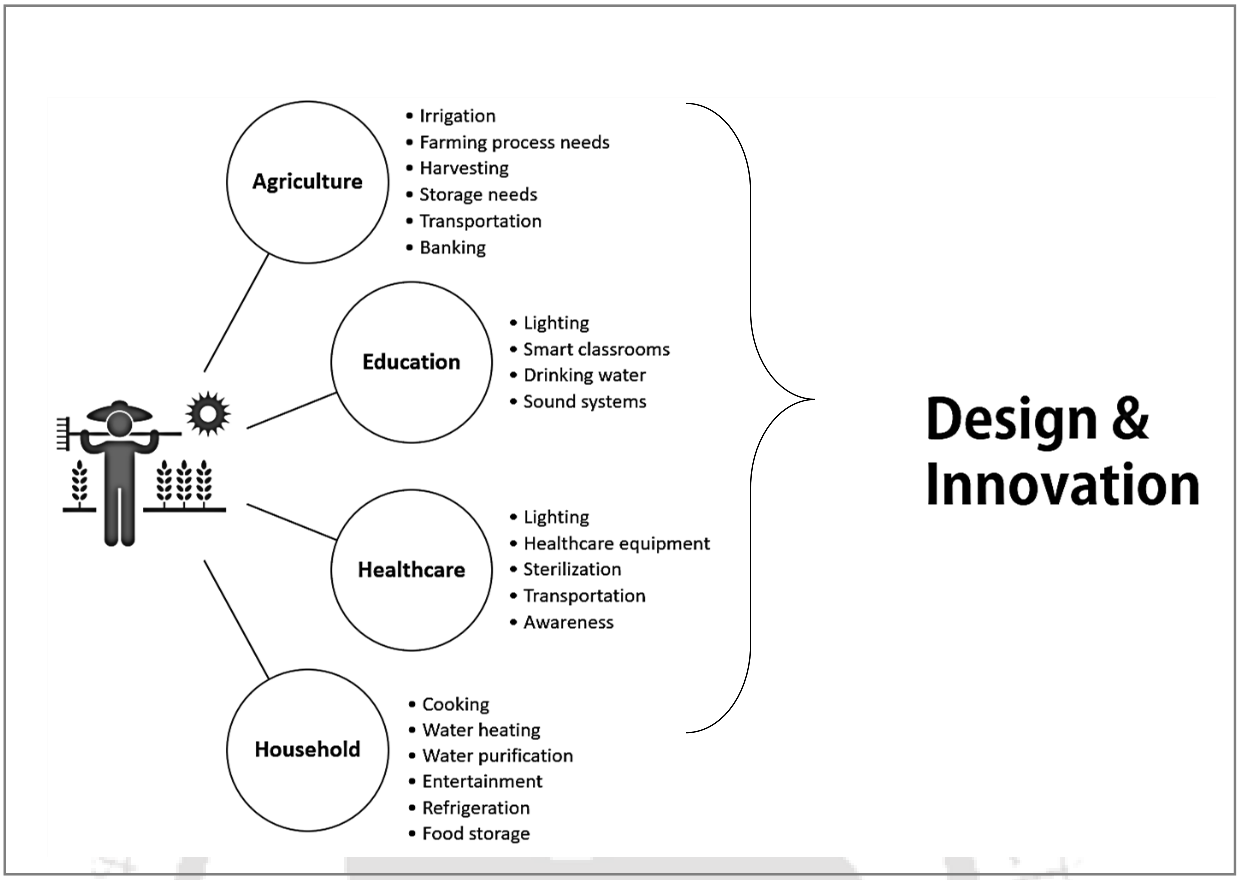


Figure 4.17 Daily Necessities of Villagers and associated activities.

These identified needs are further arranged in tabular form to frame the opportunity matrix used for further studies in two ways.

- To map the current PIPV interventions to know what activities are addressed by those interventions.
- To give direction for the problem identification for industrial designers during the conceptualization of PIPV products for the rural scenario.

4.3.5 Opportunity matrix

Figure 4.18 shows the opportunity matrix in detail. It is incremental, and a blank field can be filled after realization. The matrix helps identify specific product intervention opportunities that meet activities under the different domains.

Domain	**Requirements**	**Sub Activities and requirements**					
Agriculture	Irrigation	Water Pumping	Drip Irrigation	Distribution	Lighting		
	Farming Process needs	Land Preparations	Insecticide Spraying	Crop protection			
	Harvesting	Plucking tools	Collection devices				
	Post harvesting needs	Separation aids	Drying	Storage Needs	Protection		
	Transportation	Packaging	Carting	Movement needs			
	Banking	Applications	Withdrawals	Teller Machines	Lighting		
Education	Lighting	Indoor Lighting	Outdoor lighting				
	Smart Classroom	Projectors	Computer systems	Equipment	Sound systems		
	Drinking Water	Water purifiers	Dispensers				
	Supportive aids	Libraries	Community learning				
Healthcare	Lighting	Indoor Lighting	Special Needs	Hand equipment			
	Sterilization needs	Equipment	Tools	Sanitation			
	Transportation	Emergency needs					
	Awareness	Advertising	Awareness campaigns				
	Medical Aids	First aid kits	Equipment	Support systems			
Household	Cooking	Stoves	Lighting	Appliances			
	Water heating	Bathing	Cooking needs				
	Water purification	Drinking water	Cooking				
	Entertainment	Weather forecast	Awareness	Social life			
	Refrigeration	Food storage	Air conditioning				
	Lighting	Indoor lighting	Outdoor lighting	Emergency lights			
	Employment	Setups	Equipment	Support systems			

Figure 4.18 Opportunity Matrix for PIPV product interventions.

4.4 Summary of Field Studies

The information about the role of design intervention in India's rural and remote places is gathered from the literature in chapter two. Three case studies are undertaken to understand and review some examples of recent interventions in the field. Field visits are conducted in three villages in Maharashtra and two villages in Meghalaya to understand the ground reality and get insights into the opportunity for PIPV product interventions in rural India. This study results in generating an Opportunity matrix for the PIPV product interventions. This matrix is the output of the study described in the chapter, which forms the basis for research studies to follow in product development innovations and outline the design process for PIPV product development in the rural context.

SECTION 2

4.5 Mapping PIPV products for Need Identification

In this section 2, the research study addresses the elaborative level of design research. It first explores interventions in current offerings of PIPV products commercially available in the market and analyses them to identify the specific user needs they satisfy.

This is followed by examining product examples of grass-root innovations identified from various government portals like the National Innovation Foundation and GYTI Techpedia that were developed to meet specific needs in rural environments. Furthermore, it shortlisted a select set of PIPV based products designed by professional industrial designers to position these designed PIPV products in the context of the user needs.

All the identified products under these three categories are subsequently mapped against the five classifications of human needs following Maslow's model of the hierarchy of human needs. The distribution pattern of this mapping led to identifying the opportunity areas for design intervention to meet aspired and unmet needs of targeted rural user groups.

These findings of this study addressed Research Questions 1 and 2 of this research.

4.5.1 PIPV Product Identification and categorization

As a part of this study, 100 PIPV products are identified from various online platforms and retail outlets currently available in India (Refer to Appendix II). These are categorized under the heads: Lighting, Mobile chargers/Power banks, Decorative items and New applications. These group categories are analyzed for different product parameters to gain a holistic perspective that helps draw insights into product segmentation, Product application, Product typology, price segmentation etc. The following is summarized after analysis.

Please refer to Appendix II for the complete list of products reviewed for this study, as product images reviewed in the distribution graphs below are only indicative.

a) Product category - Product Application

As per the above classification, it is observed that 54% of the selected products fall under lighting application; 14 % are chargers, 9% are decorative items, and 23 % comprise new applications. New applications include products like a solar fountain, Agricultural sprayer, PV shavers and trimmers, Caps and bags, PV tiles, signalling systems and number plates. Figure 4.19 shows the distribution of products in five different categories.

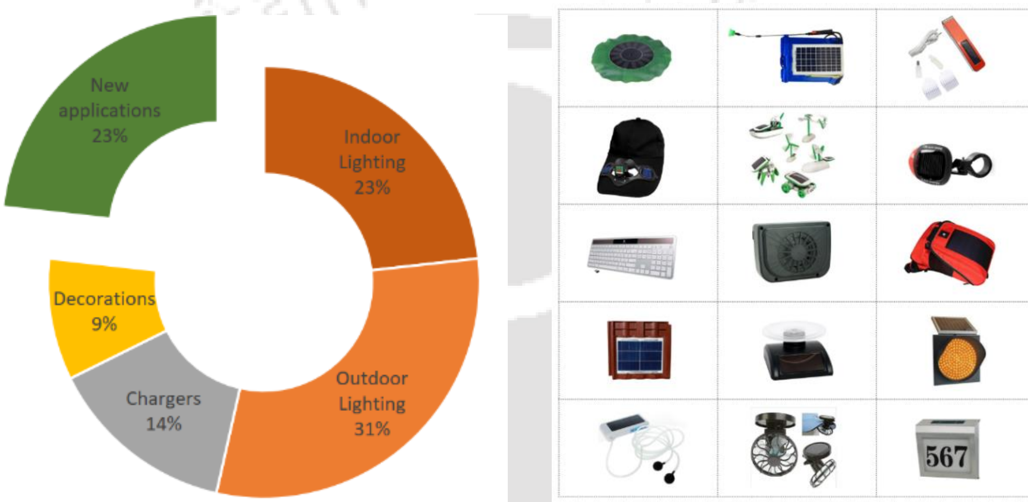


Figure 4.19 Categorization of PIPV products based on applications

b) Product category – Power source

Further, the classification is done based on the use of batteries as power storage in the system against other systems without batteries. It is observed that nearly 90% of products run on batteries, and barely 10% work without batteries. This classification becomes important because batteries are the component contributing majorly to the overall cost of PIPV products (Apostolou & Reinders, 2014). Products without batteries directly draw power from the sun and perform the intended function. However, such products become idle under no/low sunlight conditions like cloudy weather and during the night. In the case of PIPV products for lighting, it is impossible to eliminate the system's battery. Still, in the case of products for activities like the agricultural process that need to be performed mainly during the daytime, the PIPV systems can be designed and developed without batteries. Figure 4.20 shows the distribution of products in two categories; systems with batteries and without batteries.

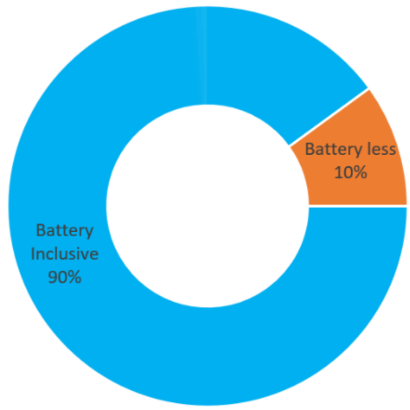


Figure 4.20 Categorization of PIPV products based on battery inclusive and battery-less PIPV systems

c) Product category – Price segment

Cost is a determining factor in the purchase choices of products. PIPV products are categorized and distributed in various price bands varying between INR 100 to > INR 5000. Figure 4.21 shows the distribution of identified PIPV products as per various price levels.

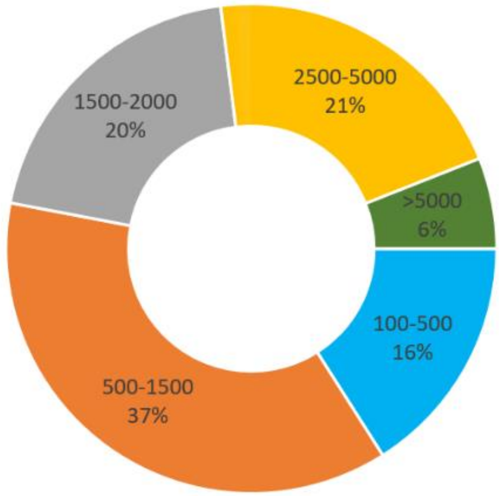


Figure 4.21 Distribution of PIPV products at various price levels.

It is observed that nearly 37% of the products lie in the price band of INR 500 - 1500, followed by 21% in the price band of INR 2500 - 5000. Very few products in the new applications category are priced at more than INR 5000. The rest, 16% of total products, are in the price group of INR 100 - 500. This categorization visualizes the PIPV product scenario from the perspective of economic aspects.

d) PIPV categorization based on Rural Activity Segmentation – Requirement capture - Product matrix

All the identified products are analyzed based on the intervention areas they address. This is done by marking the intervention area on the opportunity matrix (Ref. figure 4.18, chapter 4). The respective fields addressed by product intervention are highlighted. Figure 4.22 shows the opportunity matrix with highlighted fields by PIPV products available in the market.

	Requirements	Sub Activities and requirements					
Agriculture	Irrigation	Water Pumping	Drip Irrigation	Distribution	Lighting		
	Farming Process needs	Land Preparations	Insecticide Spraying	Crop protection			
	Harvesting	Plucking tools	Collection devices				
	Post harvesting needs	Separation aids	Drying	Storage Needs	Protection		
	Transportation	Packaging	Carting	Movement needs			
	Banking	Applications	Withdrawals	Teller Machines	Lighting		
Education	Lighting	Indoor Lighting	Outdoor lighting				
	Smart Classroom	Projectors	Computer systems	Equipment	Sound systems		
	Drinking Water	Water purifiers	Dispensers				
	Supportive aids	Libraries	Community learning				
Healthcare	Lighting	Indoor Lighting	Special Needs	Hand equipment			
	Sterilization needs	Equipment	Tools	Sanitation			
	Transportation	Emergency needs					
	Awareness	Advertising	Awareness campaigns				
	Medical Aids	First aid kits	Equipment	Support systems			
Household	Cooking	Stoves	Lighting	Appliances			
	Water heating	Bathing	Cooking needs				
	Water purification	Drinking water	Cooking				
	Entertainment	Weather forecast	Awareness	Social life			
	Refrigeration	Food storage	Air conditioning				
	Lighting	Indoor lighting	Outdoor lighting	Emergency lights			
	Employment	Setups	Equipment	Support systems			

Figure 4.22 Opportunity matrix with highlighted fields addressed by identified PIPV products

PIPV products available in the market are categorized under agriculture, education, healthcare and household activities. However, under such categorization, it is evident that there are gaps in the different activities in each head that are yet to be addressed through product interventions. These could be considered opportunities for intervention with suitable PIPV products to meet these functional activities. For instance, if we consider agriculture, the activities related to agriculture, such as land preparation, plucking tools, crop protection, and movement needs, are yet to be addressed through PIPV product interventions. It defines the scope for the product intervention to address those needs.

In the study to follow, we examine the selected PIPV products by mapping their functions against Maslow's model of classification of the hierarchy of human needs.

4.6. Maslow's Hierarchy of Needs

Abraham Maslow (1954) developed the hierarchy of needs (Maslow, 1943) (McLeod, 2007) to understand the basis of human motivation that drive these different needs (Ref. Figure 4.23)

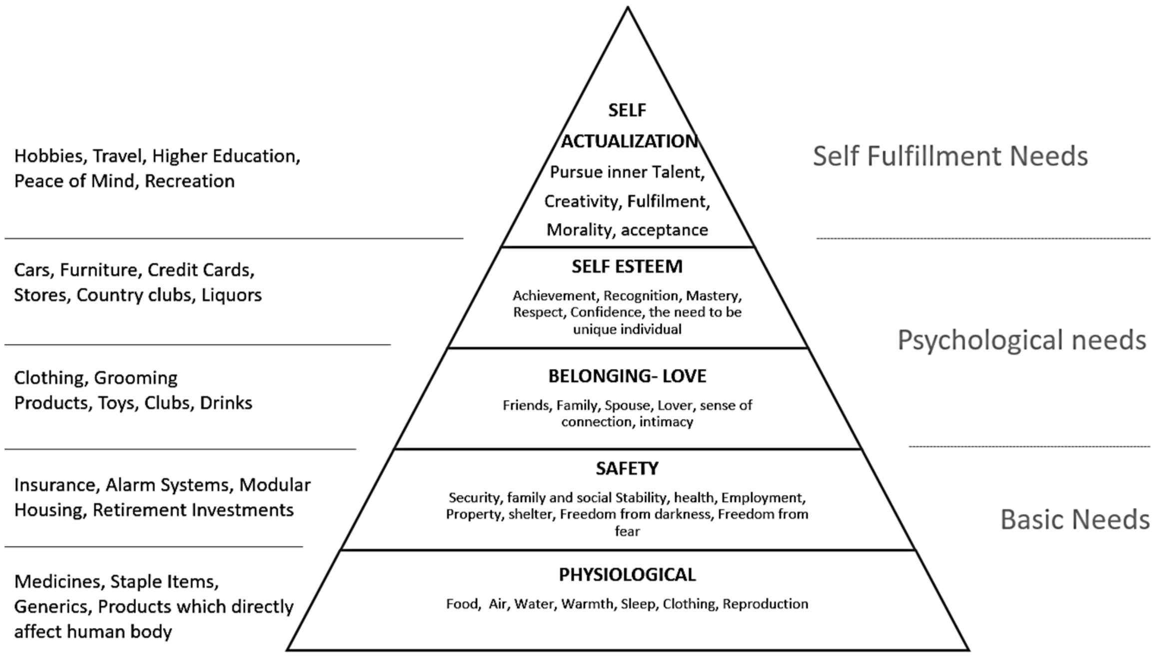


Figure 4.23 Maslow's hierarchy of needs model for various user needs

The model outlines human motivation in a hierarchal model divided into - Physiological, Safety needs, Belonging-Love needs, Self Esteem and Self Actualization. Out of these, Physiological (water, sleep, food etc.) and Safety (shelter, security, and protection) can meet basic human needs. Belonging–Love (love, friendship, and acceptance) and Self Esteem lean toward meeting psychological needs for belongingness. Self Actualization is that of Self-fulfillment of cognitive, aesthetics and self-actualization needs. Inwardly-directed ego needs include self-esteem, achievement, uniqueness, and independence. Whereas status, prestige, reputation and social recognition come under outwardly-directed ego needs. At the top is the need for self-actualization: striving to realize full potential through education, travel, hobbies, engagement with environmental/social causes, etc.

Maslow's model suggests that every individual is capable of moving up the hierarchy and constantly strives to do so. Our research argues that this premise may be an interesting way to co-relate this inherent human nature and their reflection on the desire for the different categories of products that people interact with. This becomes important for a designer who is primarily engaged in the business of translation of these 'felt' human desires into tangible features that contribute to product design features that aim to meet them. When we argue that A human-centred approach primarily drives design, this responsibility rests on the shoulders of the designer to enable the translation of such 'intangible' human-felt aspirations that must be first identified in the human need they meet before they are conceived into tangible 'designed' products that enter the market place. An analysis of mapping existing PIPV products available commercially then can become an interesting approach to assess how and what aspects of these human-felt needs have the existing products been able to meet. Based on such a premise, we have attempted to analyze and map the shortlisted products undertaken in this study against Maslow's model of human needs. These are detailed out below.

4.6.1 Methodology for PIPV product review and generation of Map Structure

In this study, the selected range of PIPV products shortlisted for this study are examined under the listed Maslow's hierarchy of human needs for analyzing and mapping the product function against the human need they aspire to meet. The same basis is extended to examine:

- A shortlisted set of Grassroot innovations developed for rural applications and
- Some conceptual examples of PIPV products developed by a selected team of Industrial designers participating in an ideation experiment.

The primary objective behind designing the map structure is to undertake a product review of PIPV products to determine the distribution of various interventions that meet diverse user needs. The three types of PIPV interventions maps include:

- The selected range of PIPV products identified from the market;

- Some PIPV innovations attempted at the Grassroot level; and
- PIPV iteration ideated by Industrial designers.

Figure 4.24 shows the three types of interventions and their respective code symbols to mark their position on the map.

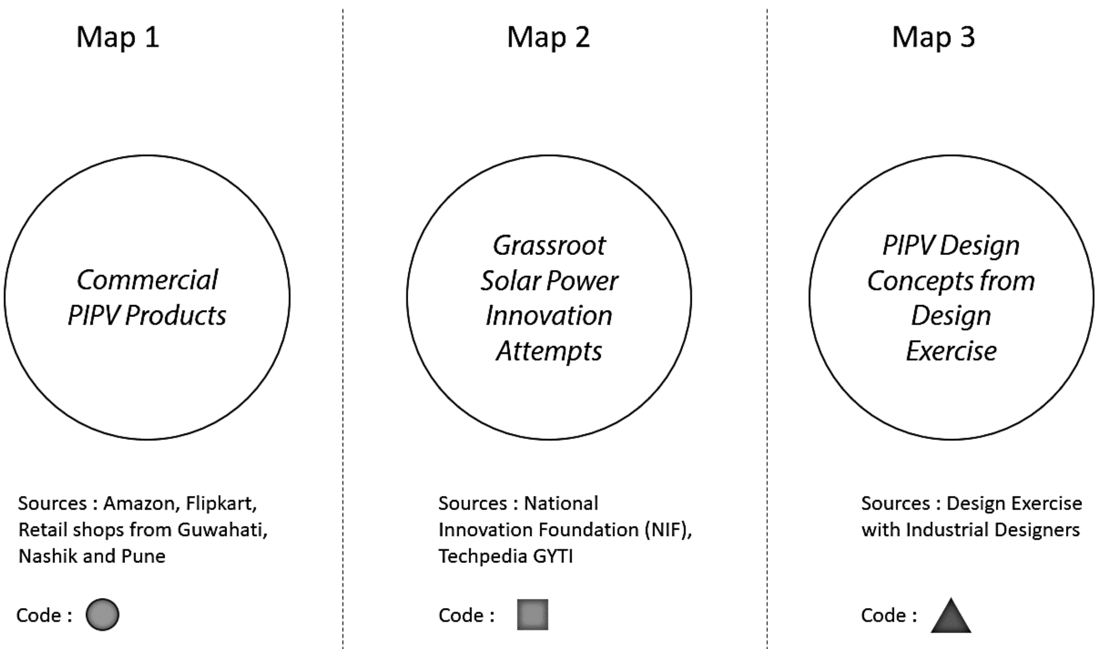


Figure 4.24 coding and mapping plan

Subsequently, the three maps generated separately under the above three interventions are integrated to comprehensively analyze holistically the distribution of all the three types of interventions and identify the opportunity gaps for intervention. Figure 4.25 shows the designed map structure described in detail in subsequent sections.

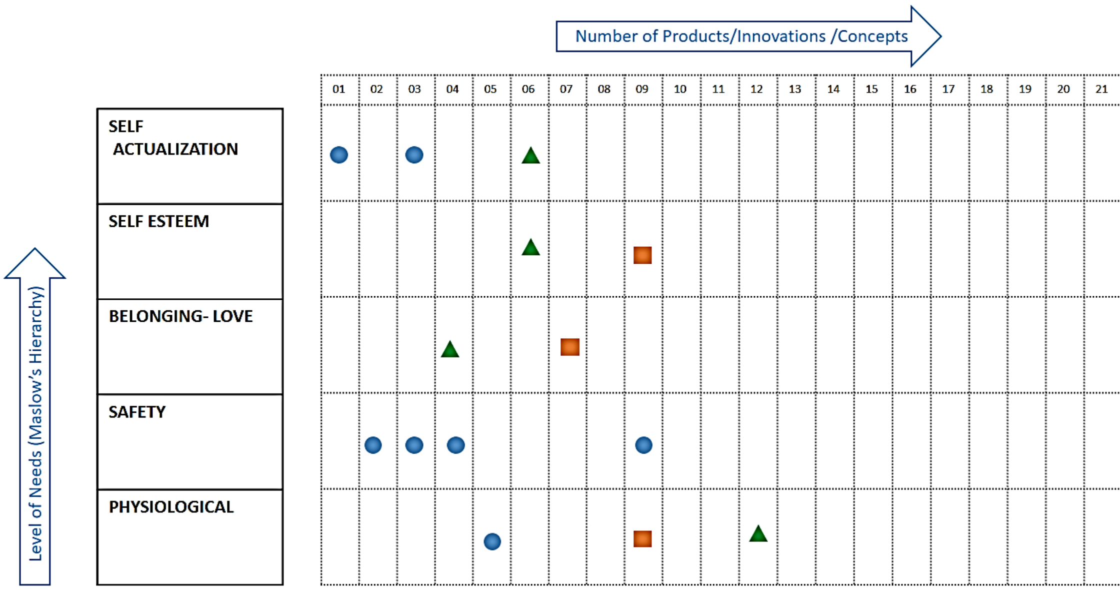


Figure 4.25 Mapping matrix structure for products and innovations and design iteration in PIPV

In the matrix, we have the five levels of Human needs placed along the vertical axis. Each of the identified products aligned on the horizontal axis and correspondingly mapped against the respective need they meet using the three codes. A sample of the integrated map overlapping all the three product categories is shown in Figure 4.25.

4.6.2 End User Perspective in Setting order of priority for PIPV interventions on mapping matrix

After designing the mapping matrix, the next step is to review the PIPV product intervention from the point of view of assessing with the targeted end-user, the importance of the need the product addressed. A Likert scale of 1-5 points was used as a measure for assessment.

Twelve volunteers in age groups 25 years and above with a minimum qualification of a graduation degree in academics were identified from the villages as the participants for this experiment. This selection criterion for shortlisting respondents was applied to get an unbiased and genuine response assessing the shortlisted product interventions on the matrix structure for the products mentioned earlier. A blank matrix sheet with product intervention details was provided to the respondent group for their assessment. The twelve volunteers who participated in this task positioned the various PIPV interventions on the matrix. The responses received on a five-point Likert scale were used to position the intervention on the matrix using the calculated mode value. Figure 4.26 shows the PIPV interventions placed on the matrix using the Likert scale method described above.

Initially, two maps are formed for PIPV product interventions identified from the market and PIPV innovations at grassroot levels.

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	
SELF ACTUALIZATION										✓												5
SELF ESTEEM																						4
BELONGING- LOVE			✓								✓		✓						✓	✓	✓	3
SAFETY	✓			✓	✓	✓	✓	✓	✓			✓				✓	✓	✓				2
PHYSIOLOGICAL		✓											✓	✓								1

Figure 4.26 PIPV interventions positioned on the matrix by using the Likert scale method

A. Mapping Commercially available PIPV Products against five heads of Maslow's hierarchy of human needs

One hundred PIPV products available commercially in the open market are shortlisted and coded with blue circles. ● These are mapped under 1A (Figure 4.27), corresponding to Products numbered 1-50 and 1B (Figure 4.28), corresponding to products numbered 51-100.

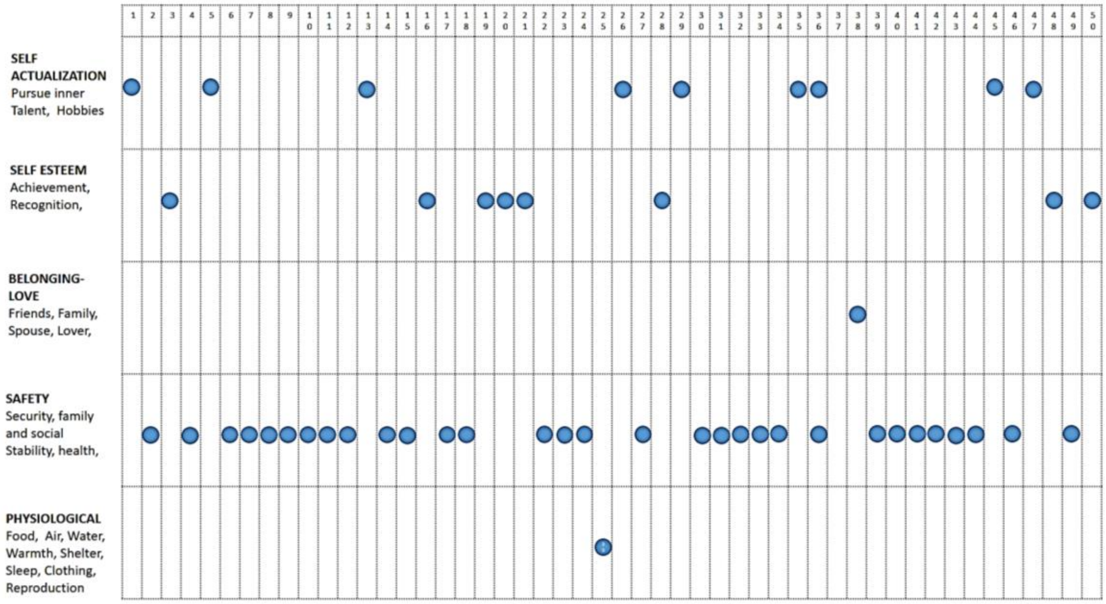


Figure 4.27 MAP 1A – Distribution of 1 to 50 products available from market.

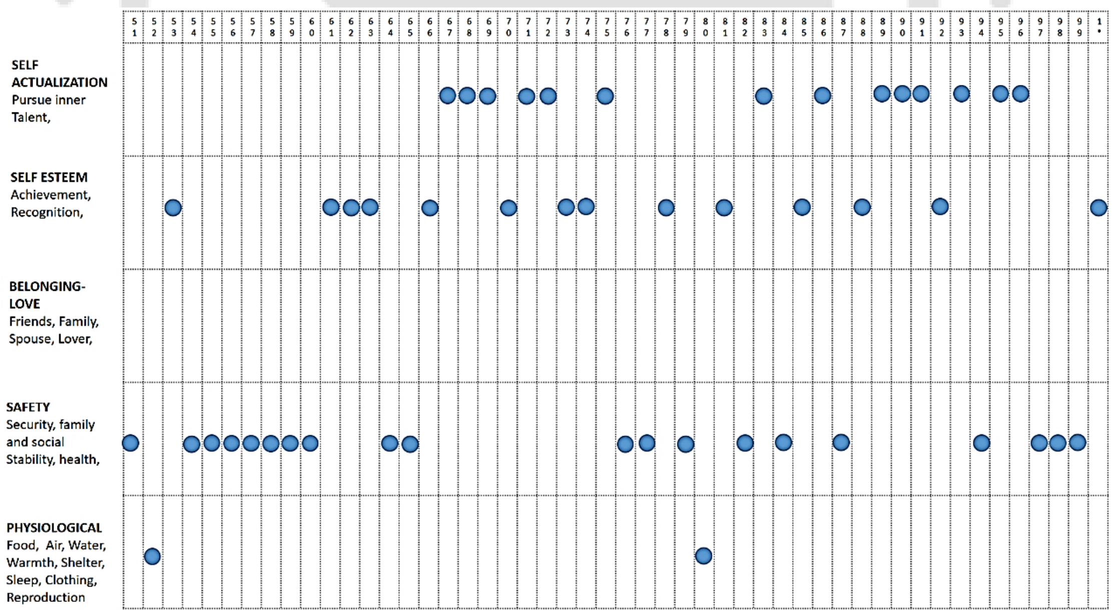


Figure 4.28 MAP 1B – Distribution of 51 to 100 products available from market.

Observing the overall distribution of commercial PIPV product interventions on the map, it is seen that most of the products fulfil needs associated with safety and security. Very few products address needs that meet basic physiological needs and the category of 'love and belonging'. From the map, one can visualize an opportunity gap for PIPV product interventions that address and meet these two categories of human needs. This clearly sets directions for the design of PIPV products that can be explicitly developed to meet the needs and aspirations of the targeted rural and remote communities.

B. Mapping PIPV Products developed by Grass-root innovators for rural needs against five heads of Maslow's hierarchy of human needs

Under this study, fifty PIPV based product innovations undertaken at the grass-root level, including successful ones and other failed attempts, are shortlisted under this study from two sources, Techpedia[4] and National Innovation Foundation (NIF, India)[5]. These shortlisted PIPV products, coded with Orange square, are mapped ■ following the same criteria outlined in the previous section (Refer to Map 2, Figure 4.29).

The map shows that the product interventions focus on addressing needs that meet physiological and safety requirements. There is little attention to interventions that meet the growth level needs of people.

The maps are used in the later part of this study to highlight the characteristics of PIPV interventions and identify experiments in product ideation that address unidentified aspirations of user needs. This will be outlined by working with industrial designers in the next section.

[4] Techpedia is an Initiative aims at putting the problems of MSME, Informal sector, Grassroot innovators and other social sector on the agenda of young technological students across India (www.techpedia.in)
[5] National Innovation Foundation innovation portal (https://innovation.nif.org.in/)

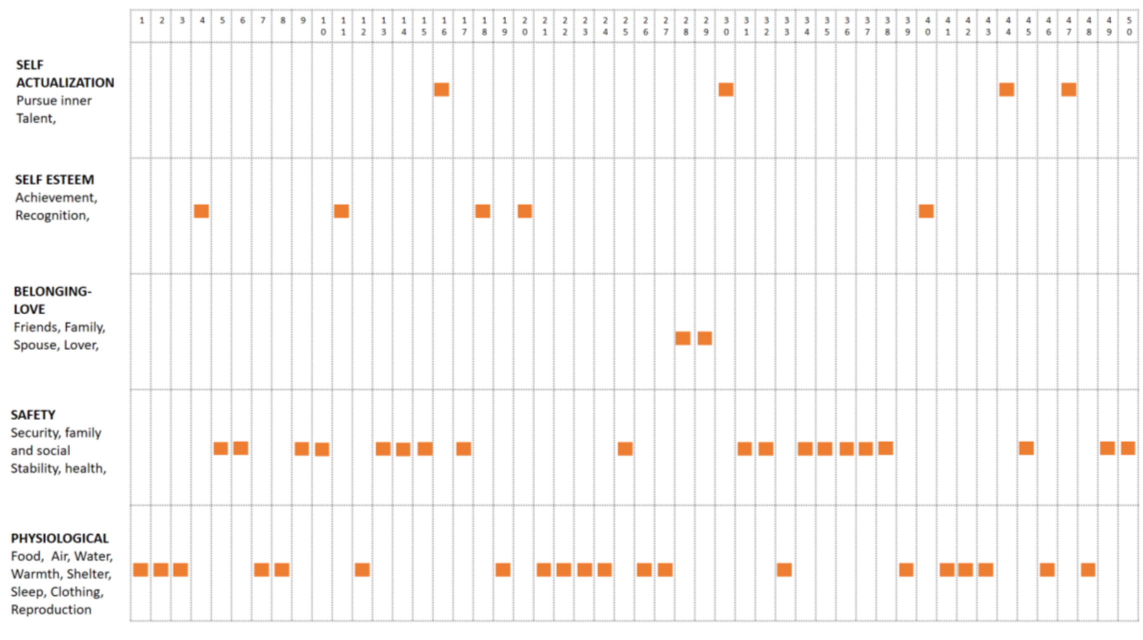


Figure 4.29 MAP 2 – Distribution of identified innovations and innovative attempts

4.7 Design Experiment I: Creative Ideation and Concept development of PIPV products by Industrial Designers

In the earlier chapters covering the literature review and the research methods, we have attempted to highlight the issues by co-relating them to the different stages of the design process that industrial designers follow. It emerged that the development of PIPV products requires considerations that are drawn from inputs from multiple knowledge domains. We posited these in the context of this research that specifically focuses on the development of products relevant that address the needs of rural communities. As the Industrial Design challenges are associated with creativity and innovation, it is anticipated that working with industrial designers will develop new applications of PIPV technology that address the needs of rural and marginal communities living in a remote location in India where there is poor or no access to electricity. In this section, we aim to develop a novel and innovative application by engaging with a select group of young Industrial designers. The group is provided with the opportunity matrix and a brief to ideate upon PIPV concepts addressing any of the activities mentioned in the opportunity matrix. The experiment design is described in the following subsection and addresses the Design ideation and conceptualization stage of the design process.

4.7.1 Selection of Industrial Designers for the Ideation design workshop

Nine Industrial designers from various parts of India responded to the call sent to participate in this experiment. All of them had one year of professional work experience in Design. The opportunity matrix was provided to the Industrial designers. They were given a brief to ideate novel PIPV product concepts for possible intervention domains drawn from the opportunity matrix other than the domain of lighting (as it is the most apparent use of Solar PV). However, they were free to ideate upon special-purpose lighting if it had any unique aspects that met specific user needs. Figure 4.30 shows the schematic for the experiment.

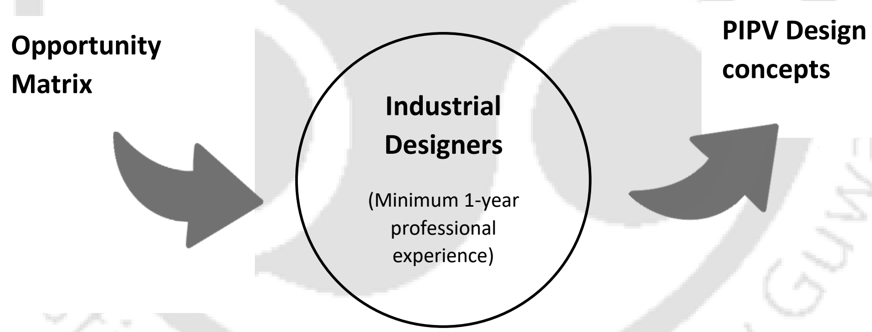


Figure 4.30 Experiment with Industrial Designers

A format for the concept sheet was provided to generate the conceptual ideas and for writing a brief description explaining their concepts. The concepts/Ideas generated by Industrial Designers are described below.

4.7.2 PIPV Concepts gathered from a design experiment

The participating nine industrial designers generated a total of nine concept ideas. The concepts were in rough conceptual sketches, subsequently converted to 3D CAD models and rendered for better visualization.

These nine concepts are elaborated in this section.

Concept 1: Solar Powered Pottery Wheel concept

Identified Area from opportunity matrix: Employment (Equipment)

Solar PV powered (PIPV) pottery wheel concept includes a solar PV panel to drive the motor of the pottery wheel. The wheel can be powered and operated either with an integrated battery system or another version without a battery system. The battery-less system can substantially reduce maintenance, operating, and manufacturing costs. However, its use will be limited to use and operate only during the day on sunny days. Figure 4.31 shows the rendered image of solar powered pottery wheel concept generated during the design experiment.

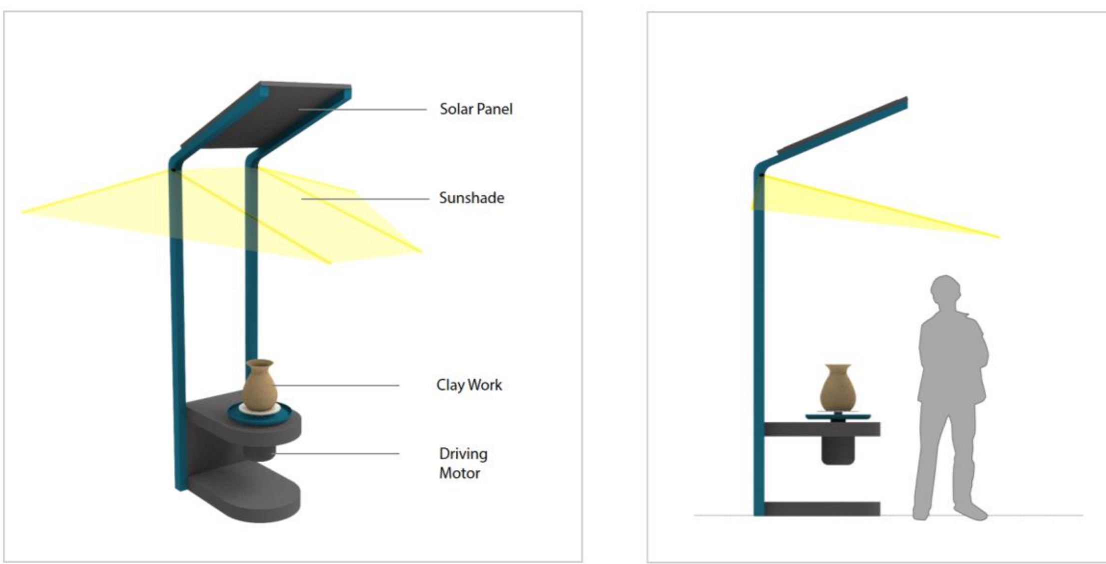


Figure 4.31 Solar PV powered pottery wheel concept.

A retractable and adjustable sunshade extends comfort for the potter. The product is modular and can be packed in a small box for transport and portability. The solar panel is kept inclined for maximum efficiency. This pottery wheel system avoids the dependency of pottery work on intermittent electric supply. The product is conceptualized by addressing the employment need mentioned in provided opportunity matrix.

Concept 2: PIPV bicycle tyre Inflator

Identified Area from opportunity matrix: Mobility needs

Bicycle is a common mode of short-distance transportation in the rural scenario. Bicycle tyres need air inflation periodically. The concept is a PIPV air pump to inflate bicycle tyres. The concept could be conceived as a community use product based on the entrepreneurship (Pay per use) model, as it may prove expensive for individual purchase. The concept was inspired by drawing from the domain of movement needs mentioned in the opportunity matrix for the rural scenario. Figure 4.32 shows the rendered image of the solar-powered bicycle tyre inflator concept generated during the design experiment.

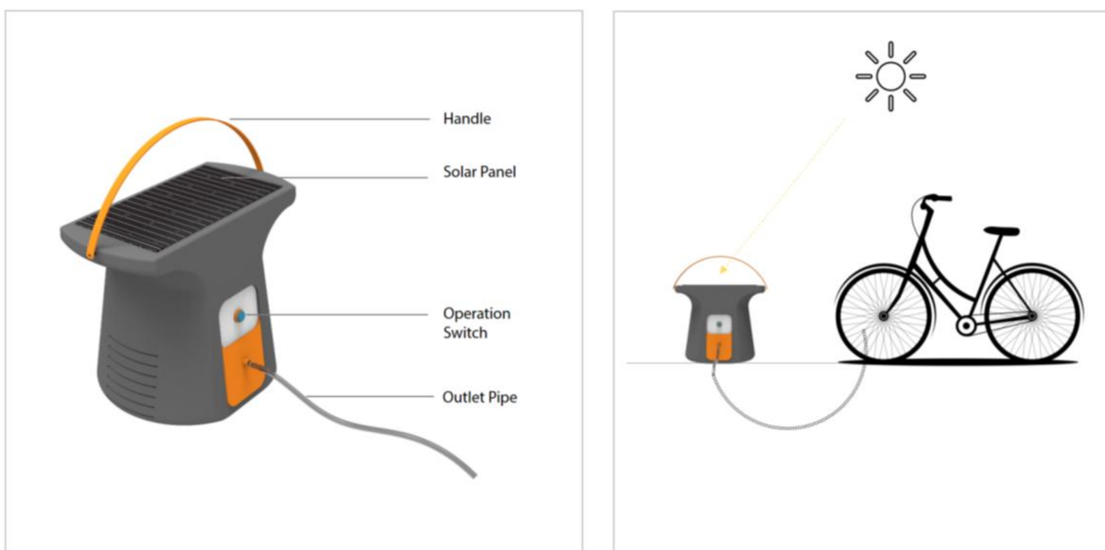


Figure 4.32 PIPV bicycle tyre inflator concept

Concept 3: Solar Powered Fish Pond Oxygenator (Aerator)

Identified Area from opportunity matrix: Farming Process needs (Equipment)

Figure 4.33 shows the solar PV powered fish pond oxygenator.

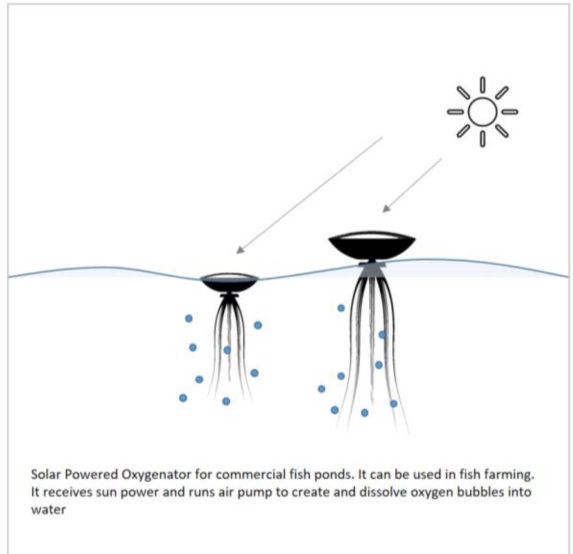


Figure 4.33 PIPV fish-pond oxygenator

Fish farming is often practised in small ponds in several rural villages in India. In most villages, fish farming is done by constructing artificial fish ponds or using the bio flock technique in which fish are grown in a controlled environment. Sometimes, these ponds lack a supply of oxygen due to the high density of fish. Also, for the healthy growth of fish, a continuous supply of oxygen is necessary. The PIPV Solar PV powered fish pond aerator is conceptualized as solar-powered. It delivers oxygen to fish in such commercial fish ponds. The concept iteration addresses Farming Process needs (Equipment) identified from the opportunity matrix. The PV aerator concept can be effectively used for outdoor fish ponds. The tentacles of the product go deep to the bottom of the pond and deliver oxygen effectively. Being a standalone electricity-independent product, it is helpful for active farmers in fish farming.

Concept 4: PV Nebulizer for PHC Centre

Intervention Area: Medical Aids (Equipment)

Figure 4.34 shows the solar PV powered nebulizer concept

Figure 4.34 Solar PV powered nebulizer.

Most people staying in rural and remote areas depend on Primary Health Centre (PHC) for healthcare that provides basic medical facilities. Irregular and interrupted electric supply at these locations makes essential medical equipment like an electrically operated nebulizer non-reliable. The proposed PV-powered nebulizer will charge the battery using Solar PV power, making it more reliable than the grid electricity operated product. Also, the integration of PV power in the product makes it highly portable, making the product advantageous for healthcare workers to carry and treat patients in their homes. This product was conceptualized as addressing the requirements of medical aids (equipment) from the opportunity matrix.

From the experiment, the Designers could generate various concepts to address multiple activities from the opportunity matrix provided to them. Four were presented in the form of concept renderings. The other five PIPV products conceptualized by the designers are listed in Table 4.1 below.

Table 4.1 Remaining five concepts from the design experiment

Sr. No.	Concept	Intervention Area	Function
5	Solar-powered Digital Clock for schools	Education (Equipment)	PV panel integrated watch for learning and time indication.
6	PV powered water sprinkler	Agriculture (irrigation)	PV-powered battery-less water sprinkler system.
7	Solar Fan Equipment for agricultural processes needs	Agricultural (Farming process needs)	PV powered air blower for use in various agriculture-related activities.
8	Solar Community spaces for night classrooms and gathering	Education (Community Learning)	Public place product with solar lighting and sound systems for night schools and gathering
9	PV Awareness System	Entertainment (Awareness)	Display of information in public places using Solar-powered displays.

The nine concepts generated by Industrial designers are then mapped on the same map structure described in section 4.6.1 of the current chapter. The same method of mapping as adopted for earlier mapping is used. Figure 4.35 shows the map structure on which nine design concepts are marked as per the user needs to be addressed.

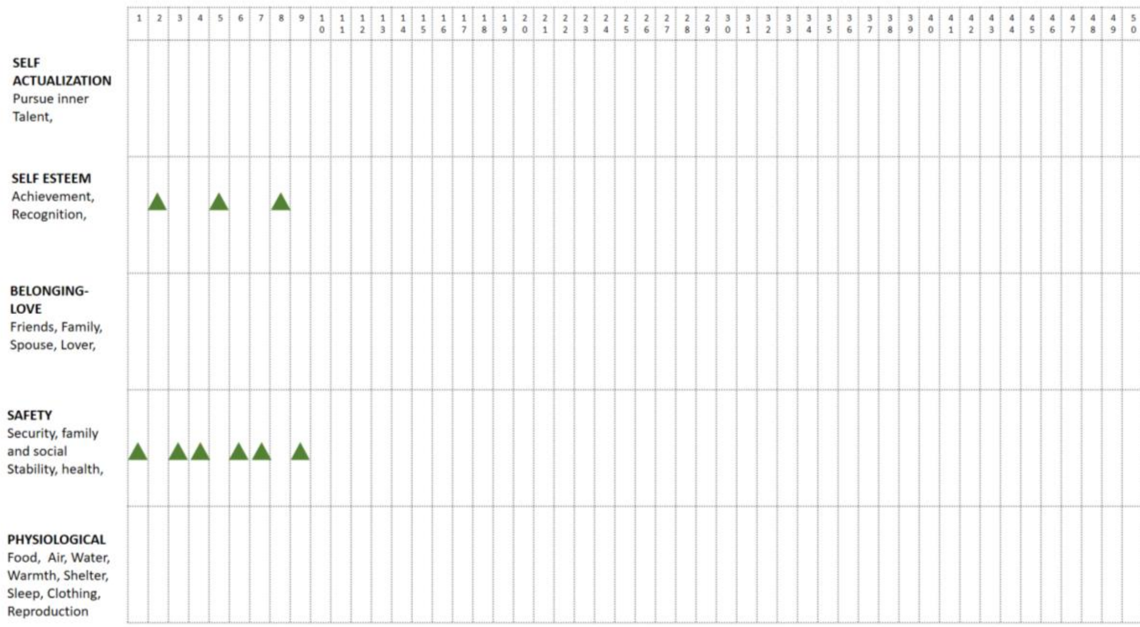


Figure 4.35 MAP 3 – Distribution of PIPV concept generated by Industrial designers during design experiment

At this stage of the study, three maps are available – Map 1 for PIPV products identified from the current market, Map 2 for PIPV innovations or attempts to innovate at the grass-root level, and Map 3 for design concepts generated by industrial designers during the design experiment.

Each of these three maps gives insights into the user needs to be addressed through this individual type of intervention. All the maps are superimposed into one to get a comprehensive overview of these insights. Figure 4.36 shows the overlapped version of the map. Various observations can be made that give inputs about the various user needs that can be satisfied by multiple PIPV product interventions. This ultimately aids in visualizing the directions for PIPV interventions, specifically in rural India.

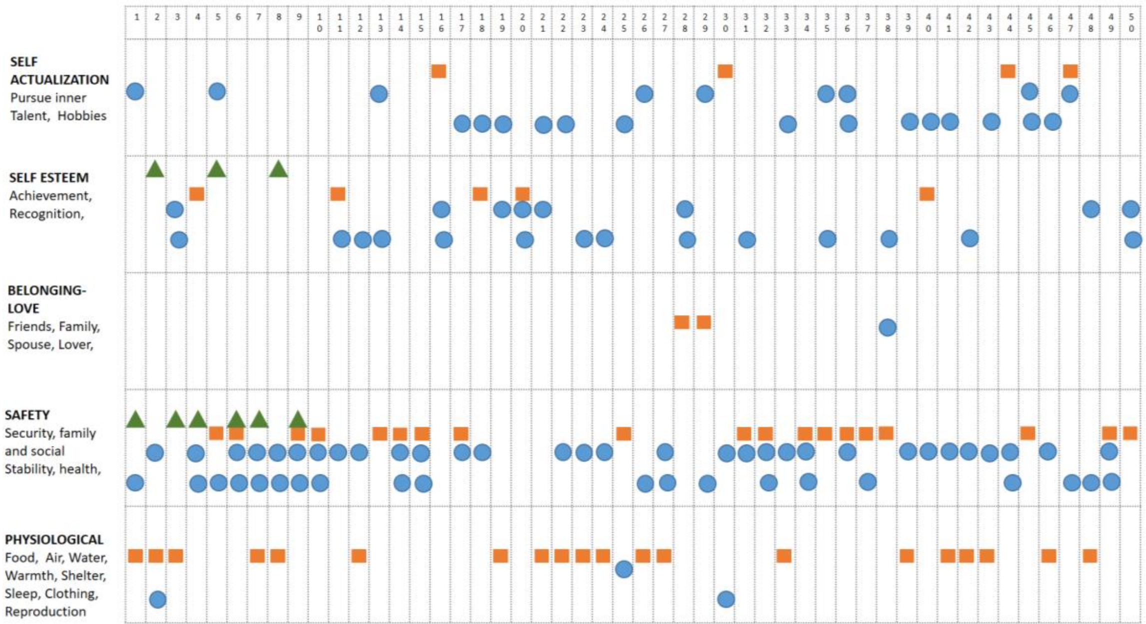


Figure 4.36 Overlapping of Map1A, Map1B, Map2 and Map3

In the Opportunity Matrix (Figure 4.37), we compare ideas generated from the experiment with industrial designers (who generated concepts using the opportunity matrix) with the PIPV products commercially available.

	Requirements	Sub Activities and requirements			
Agriculture	Irrigation	Water Pumping	Drip Irrigation	Distribution	Lighting
	Farming Process needs	Land Preparations	Insecticide Spraying	Crop protection	Equipment
	Harvesting	Plucking tools	Collection devices		
	Post harvesting needs	Separation aids	Drying	Storage Needs	Protection
	Transportation	Packaging	Carting	Movement needs	
	Banking	Applications	Withdrawals	Teller Machines	Lighting
Education	Lighting	Indoor Lighting	Outdoor lighting		
	Smart Classroom	Projectors	Computer systems	Equipment	Sound systems
	Drinking Water	Water purifiers	Dispensers		
	Supportive aids	Libraries	Community learning		
Healthcare	Lighting	Indoor Lighting	Special Needs	Hand equipment	
	Sterilization needs	Equipment	Tools	Sanitation	
	Transportation	Emergency needs			
	Awareness	Advertising	Awareness campaigns		
	Medical Aids	First aid kits	Equipment	Support systems	
Household	Cooking	Stoves	Lighting	Appliances	
	Water heating	Bathing	Cooking needs		
	Water purification	Drinking water	Cooking		
	Entertainment	Weather forecast	Awareness	Social life	
	Refrigeration	Food storage	Air conditioning		
	Lighting	Indoor lighting	Outdoor lighting	Emergency lights	
	Employment	Setups	Equipment	Support systems	

Figure 4.37 Requirements and sub-activities addressed by Industrial designers

The red areas highlight the issues met by commercially available PIPV products. At the same time, the green fields depict the intervention areas considered for concept generation by Industrial designers during the design experiment. It is observed that Industrial designers were able to address more broadly unexplored domains of need requirements not yet addressed by commercial PIPV products. The chart shows that there are unmet opportunities in the domains of agriculture, education, healthcare and household activities that PIPV product interventions can meet. The opportunity matrix can be the source to trigger ideas for PIPV intervention relevant to the rural context of need.

4.8 Observations

The series of experimental studies helped us in making the following observations about the contributions that PIPV products make or potentially can make in meeting targeted end user's needs:

From the Integrated map matrix, it is observed that most commercial PIPV products satisfy the safety and security level needs of users. Following Maslow's hierarchy of human needs, most products are distributed on the top portion of the matrix, satisfying self-esteem and self-actualization level needs. Products are sparsely distributed in the bottom and middle regions, with very few of them satisfying basic physiological and Belonging level needs.

- Grassroot innovations and innovative attempts in PIPV are distributed in the bottom region. Most of the interventions in meeting rural needs have attempted to address basic physiological needs, and their number is more in this segment than the commercially available products. Also, very few satisfy the need category of love and belonging needs.

- Design concepts ideated by industrial designers have attempted to satisfy the needs of safety and self-esteem. Concepts received from the exercise are novel and focus on new applications of PV technology. They can be considered to meet the bottom segment of basic physiological requirements that are crucial in the rural scenario.

These observations indicate that it is necessary to direct the development of PIPV products in a more focused manner towards satisfying the basic physiological and safety level of needs and ensure the availability of context-appropriate PIPV products that will boost the quality of life of people in rural areas.

In the next phase of the study, we focus specifically on aspects of the assessment process of Industrial design of PIPV products following the Spider web graphical approaches in published literature. Based on that, design experiment II is framed. Details of this is outlined in the next section to follow.

SECTION 3

4.9 Assessment of PIPV products

Any product needs to fulfil the user requirements and the function for which the product is designed and developed. User requirements depend on the ecosystem in which the user is located. For the targeted end-users, the factors that must be considered while designing Products and services are specific to rural conditions in India. Assessing these requirements in the form of assessment indicators will help the design and development process of PIPV products.

4.9.1 Framework for assessment of PIPV products for Rural scenario Using Spider web Graphical method

A study conducted by Tomothi Whitehead et al. (Whitehead, 2015) examined the underlying reasons for the lack of uptake of products such as cook stoves, water filters, etc., developed to improve people's quality of life in developing countries. They identified indicators from a literature review, an analysis of sixty-three different products and eighteen interviews with product designers and NGOs. The outcome of their study concluded with outlining a framework for assessing products consisting of eight critical indicators for product success. These indicators are:

1. Affinity – Affinity is the connection that users have to the product. This indicator comprises cultural appropriateness, being proud to own the product and financial investment.
2. Desirability – The nature of a global economy means that users in developing countries are equally exposed to the styles, fashion and types of products seen in the developed world. Consequently, if goods and services are designed to lower quality, they will be noticed and affect product uptake and long-term use.
3. Reparability – a product purchased by people represents a significant investment. Therefore, it is essential that products be repaired or returned when failures occur. Either product are designed to be repaired by local craft or merchants, or alternately, they can be supplied with a warranty to receive a replacement.
4. Durability - wear rates are higher, and products need to be designed and built with higher durability and robustness than similar products in the urban context.
5. Functionality - Typically, users neglect products that fail to provide their functional expectations. Functionality is an essential factor to be considered while thinking about the rural context
6. Affordability – many people have limited income, and hence it is crucial to consider their buying capacity while limiting the cost of the product.
7. Usability- The nature of designing for developing countries requires that products be easy to understand and useable across different cultures and languages. Product analysis revealed that many products come with picture diagrams showing how they work and how to use them. It is effective, but it is essential to embed usability into the core design of the product.
8. Sustainability - Sustainability has been split into two parts; firstly, it is essential to consider environmental sustainability in material choice, end of product life and overall ecological costs. Secondly, the product distribution needs to be sustainable within the existing economic market. Evidence from interviews suggests that if products are distributed for free in the same markets where locals sell similar items,

this skews the markets and reduces the demand for sold products. Locals will often wait for the free product, even if this harms their health or livelihood.

Apart from these eight indicators, the indicator of acceptability was mentioned in another study (Whitehead, 2014)

9. Acceptability - Social and cultural issues vary from country to country, which can play an essential role in adopting new products. The diverse nature of Indian culture makes this factor important to consider.

The paper proposes using these eight indicators as a means for product assessment in which each indicator is graphically assessed on a scale of 1-5 using the Spider web graph shown in Figure 4.38.

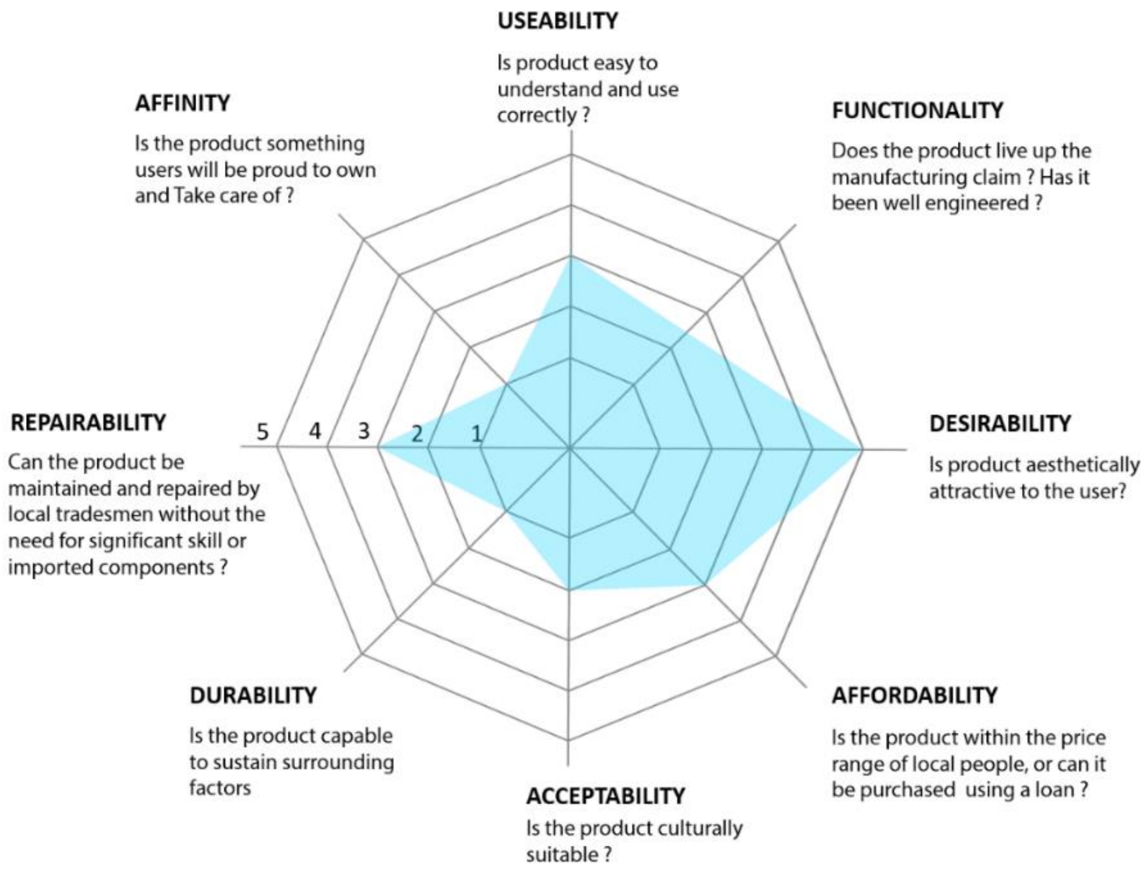


Figure 4.38 Spiderweb assessment model for PIPV product assessment (Whitehead, 2015).

Spiderweb assessment method can be adopted for multiple assessments described below:

A. PIPV Product assessment for design improvement

This spider web model rates the various identified PIPV products on identified indicators. A five-point scale is used in a survey to get the responses from the respondents from the targeted rural respondents. The final judgement is marked by considering the mode value of received responses. An example below is the assessment of a PV powered portable torch.

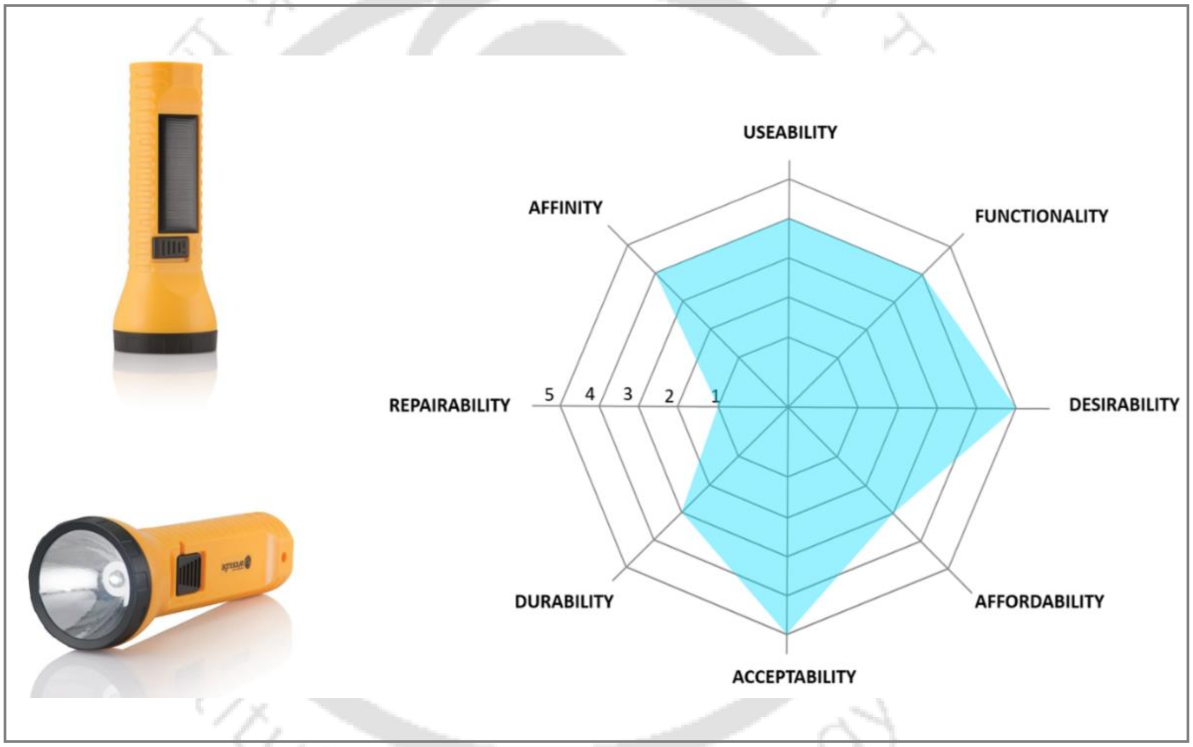


Figure 4.39 Spiderweb assessment of PIPV torchlight.

Here, the spiderweb plot shows the characteristics of PV powered torch. The plot indicates that the repairability and durability of the product need to be improved due to their low ratings; however, the product has a high level of acceptability and desirability, with fair ratings on affinity, usability, and functionality. Model is helpful in assessing the PIPV products to know about the factors that are lagging or bottlenecks for design improvements.

B. Comparative evaluation of a PIPV Product

The spiderweb assessment model helps evaluate a product by comparing it with already existing products of similar function. Various lagging factors can be identified to redesign and improve the product with respect to the available solution. As a part of the study few products, including a Pakijha solar PV lantern, a Rechargeable table fan, and high bright LED light, were given to the users. After using those products for a week, their responses are recorded to analyze the developments using the spiderweb assessment method. Testing and assessment of pakijha solar latten are shown below in figures 4.40 and 4.41

Figure 4.40 Testing of Pakija PIPV lantern with users

Pakija lantern is a PIPV product designed in the shape of conventional kerosene lamps. The lantern is entirely operated by solar PV power as it has a circular-shaped solar PV panel on its top. The product also provides a mobile charging plug to make it multifunctional to a certain extent. The product has a dimming function with three modes to vary the light intensity. Blue light is also offered in the night mode, so the product can also be used as a night lamp. This lantern is available for INR 350 to 450 with various colour options. The product has a weak plastic body and is easily breakable compared to the metal body of conventional kerosene lamps. The Pakija lantern is then assessed using the spiderweb assessment method based on the feedback received from the users. At the same time, the conventional rechargeable electric lantern is also evaluated to compare both of them on one overlapped spiderweb model, as shown in figure 4.41

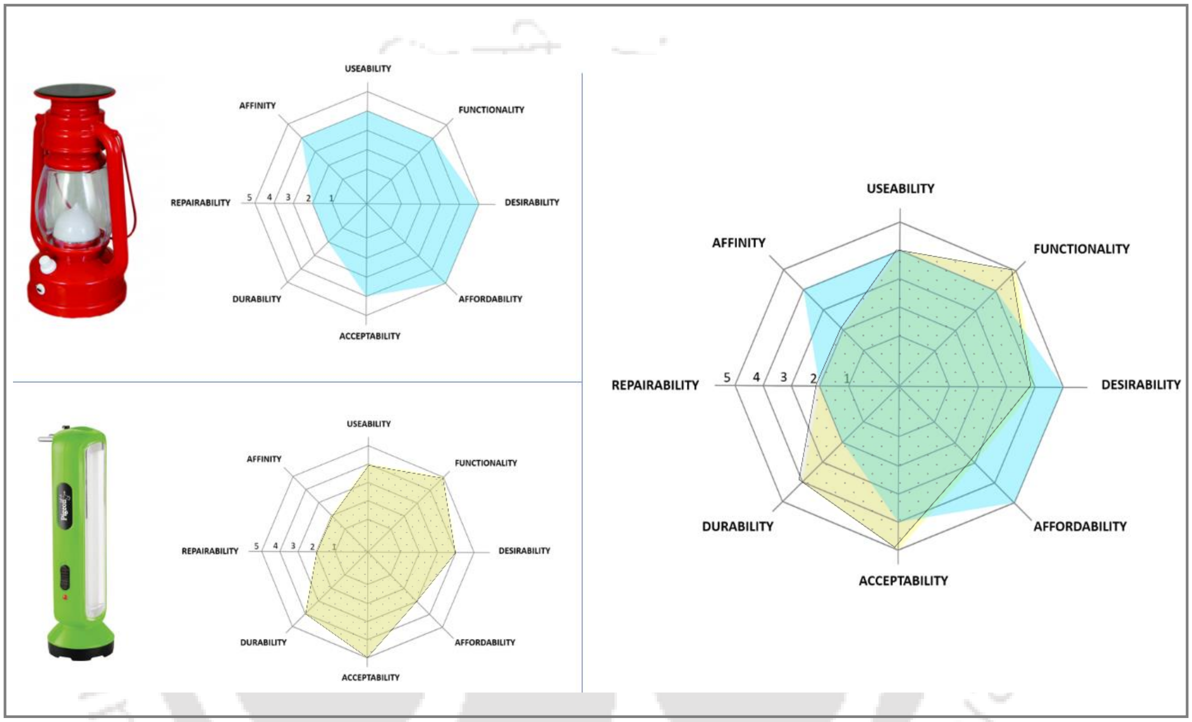


Figure 4.41 Spiderweb assessment of Pakijha solar lantern and comparison with other product

According to this, the Pakijiha lantern is superior in affordability, desirability, and affinity for users. At the same time, the conventional rechargeable emergency lantern is comparatively durable, functional and acceptable to users. Both the products lag in repairability, so this factor can be improved while considering a redesign of a particular product. This type of assessment of PIPV products helps compare various concepts with each other. In some situations, the existing PIPV products might need to be redesigned for their work using Solar PV power. In that scenario, the product can be analyzed using the spiderweb assessment method to identify the areas of improvement for redesigning the product. The solar PV tile for the roof is assessed using the spiderweb assessment method and compared with the conventional roof tile.

Similarly, the PV AM/FM radio is compared with a conventional AM/FM radio. Such comparative studies made using the spiderweb method give insights into the pros and cons of PIPV products over conventional products. Figure 4.42 and 4.43 shows this assessment.

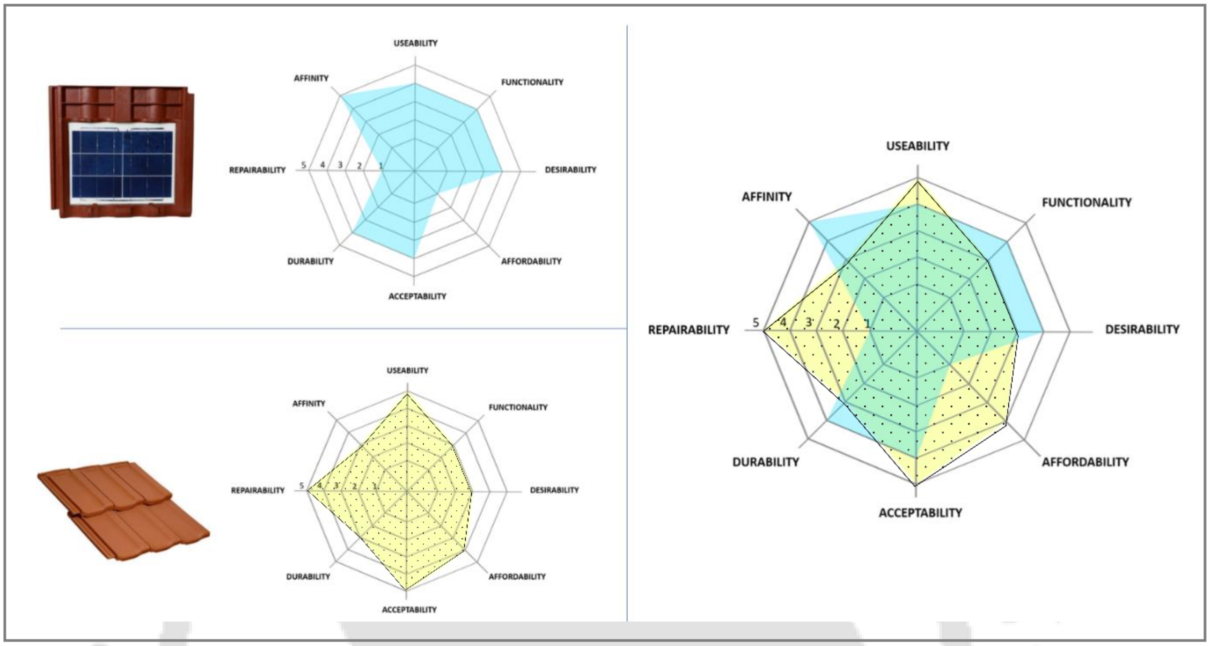


Figure 4.42 Spider web assessment of PV roof tile

Assessment of solar PV roof tile and conventional terracotta roof tile; spider web model shows that PV tiles are not affordable to the users and pose reparability issues. Below is the spider web assessment of PV FM Radio

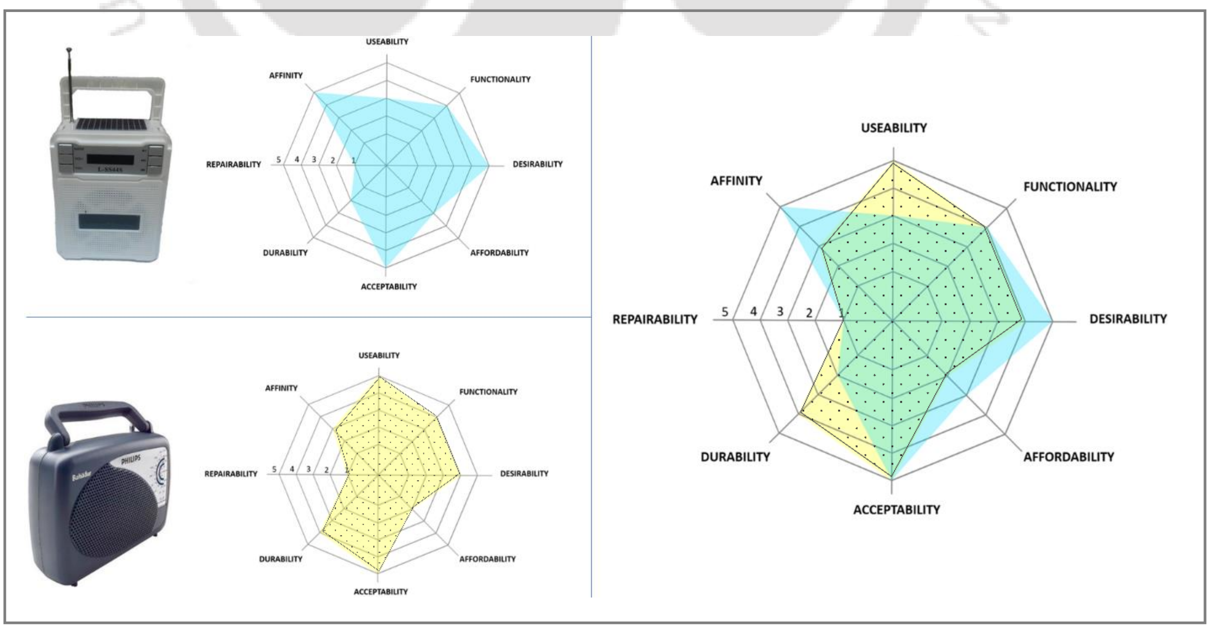


Figure 4.43 Spiderweb assessment of PV FM radio

C. Spiderweb assessment for PIPV concept evaluation

Concepts generated during design exercises conducted in earlier studies were analyzed using the spider web evaluation method to know the characteristics of concepts. Following this model for assessing concepts will lead to the rectification of concepts in the earlier design phase.

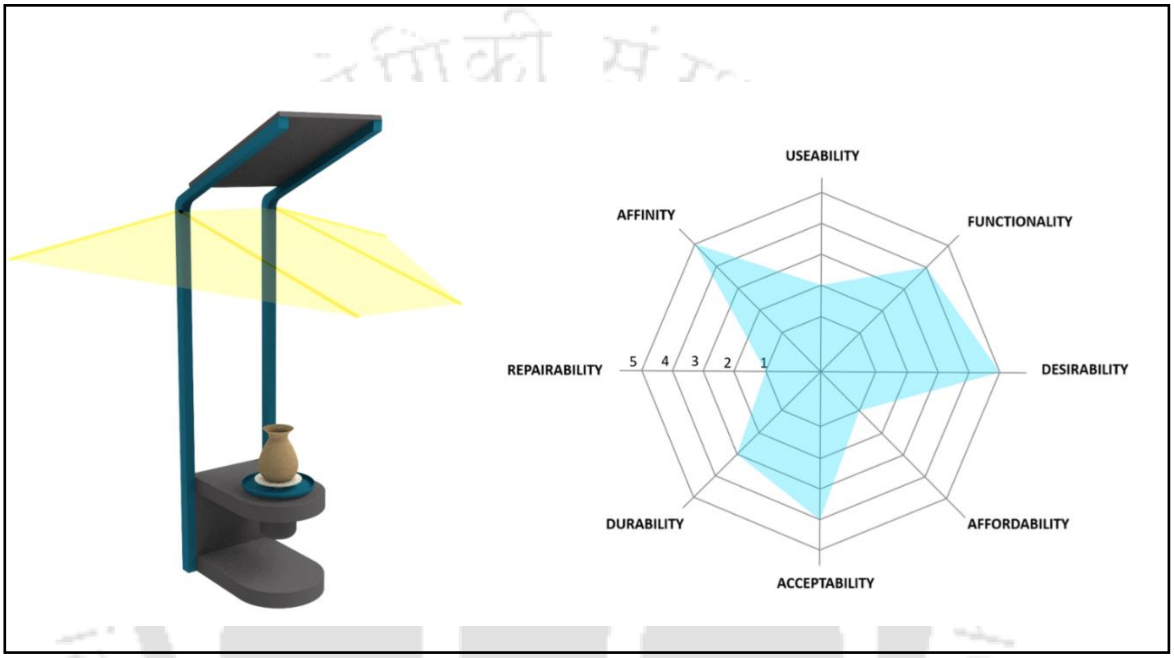


Figure 4.44 Spider web assessment of PIPV concept of the Pottery wheel

PIPV concepts generated during the design exercise were analyzed using the spider web assessment method to determine the improvement areas of the concepts. The analysis of the spider web graph for PV powered pottery wheel shows that the concept lags in affordability, reparability and usability but possesses a high affinity and desirability. The model will be effective in analyzing concepts before selecting. The adopted assessment model can be helpful for different types of PIPV assessments in rural India.

Summary:

The open-ended nature of the different experimental studies undertaken until this stage of the research must be noted in terms of research methods used during the different stages of the design development process for PIPV products in the rural context. The insights drawn contribute to enriching the designer's understanding of the product development contribution they make. Figure 4.45 shows the funnel diagram for the design experiments contributing to the divergent nature of enquiry in the design process.

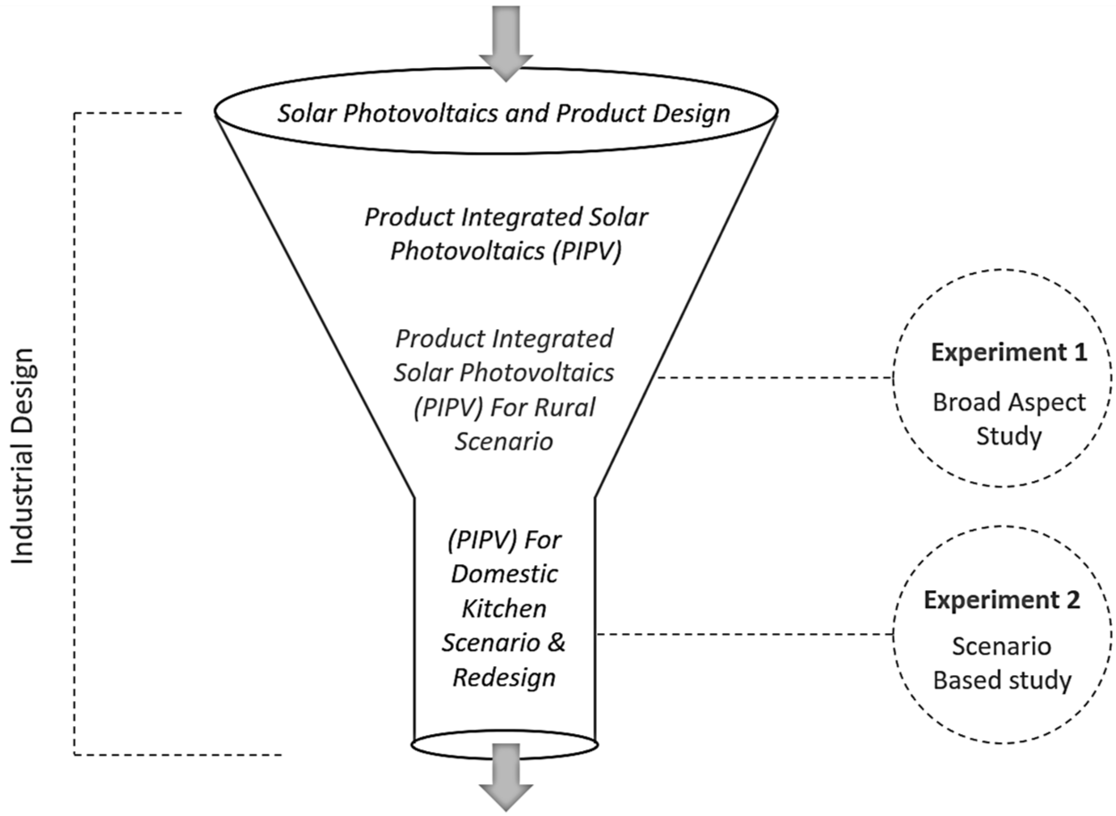


Figure 4.45 Funnel diagram for design experiment narrowed down for research studies.

In the next section to follow, we undertake a scenario-based design conceptualization experiment conducted with Industrial designers explicitly focused upon a more convergent focus specific to a real-world scenario. Such a scenario-based study focuses on the specific application of the design process in developing PIPV products to meet a specific need. The scenario examined is the domestic kitchen needs of a rural household in a village setting. In the subsequent studies of the research, we apply context-specific methods to conceptualize, develop and evaluate the concept prototype after testing with users.

SECTION 4

4.10 Experiment in Scenario-based approach to Product Conceptualization, Development and Realization

This concluding section of the chapter addresses the technical aspects that affect the creative ideation and product conceptualization phase of the design process for a scenario-based context. It draws from field observations and studies of the kitchen environment in Indian villages where women spend time attending to kitchen activities and household chores.

This kitchen scenario forms the basis for outlining a creative design experiment for a selected group of designers. It examines how understanding technical aspects can impact the creative outcome of product ideas generated when they are tasked with generating design solutions that address the issues women face while working in the kitchen. One group generates ideas given technical hint sheets that support them with information on technical specifications for PV, while the other group works on generating ideas without the aid of the technical hint sheets. The experimental study compares the outcome of the feasibility of the ideas generated by the two groups. It draws conclusions justifying the need for supporting aids such as the technical hint sheets to help designers generate more feasible and realistic solution proposals that are feasible to produce.

4.10.1 Introduction – the challenges in Industrial design of PIPV products: insights from the literature.

Developments of all PIPV products involve multiple electronic components that help perform the product's desired function. The PV panel is the solar-power generating source of the product and must be incorporated into the product. Understanding the technical specification in selecting solar PV panels is crucial in designing any PIPV based product to perform its desired function. It becomes a major deciding factor that dictates the overall design of the PIPV product. Due to current technology, rigid solar PV panels are readily available, economical, and widely accepted. Its incorporation into the product affects its form, and the size of the PV panel defines the amount of power available for the product's function. Earlier studies from published literature have identified the technical challenges and barriers to the industrial design of PIPV products and suggest a framework to aid the idea generation process. In his study, M. Veefkind (Veefkind, 2004) identified an understanding of the product's energy balance as the significant barrier to the development of Solar PV products. Analyzing the case of the solar PV computer mouse conceptualized by industrial designers, they found that the energy input was not fulfilling the load demand of the product. The study raises the question of insufficient technical information about the selection of compatible solar panels during concept generation to fulfil the energy demand of the product. These issues in the product development process result in later rejection of ideas. Ultimately it affects the lead time for the product to come into the market and must be addressed.

In continuation to this, B. Flipsen et al. (2004), in their study, highlight the difficulty designers face in understanding the available data in technical sheets during the concept and system-level design phases of the design process. It is often found that these specifications cannot be used and should be translated into more usable parameters (Flipsen et al., 2004). They proposed an idea of 'translation interface', which is a coupling between what is available in the technical knowledge base and what the designer wants to know when designing consumer products embedded with an alternative power source like Solar PV. These studies highlight the data requirements about the solar PV panels in the interpretable form for the concept generation of PIPV products.

Figure 4.46 shows the schematic interface that must aim to communicate technical data into accessible and useful parameters for design engineers and industrial designers. In this study, an attempt is made to create such a translation interface to assist Industrial designers to easily access interpretable technical data on PIPV during the concept generation phase.

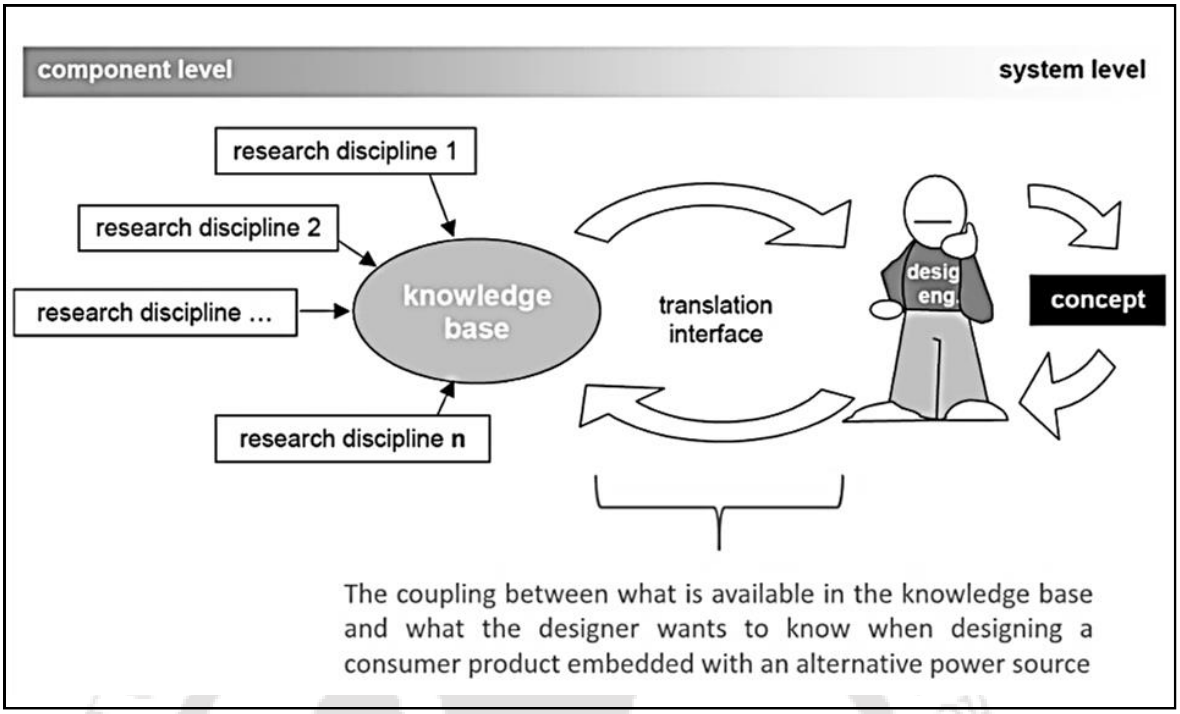


Figure 4.46 An interface to communicate technical data into accessible and useful parameters for Design Engineers / Product designers (Flipsen et al., 2004)

To validate this, design experiment II is designed with two groups of Industrial designers with different inputs to each group to work on the same assignment. For this, the design brief is formulated considering the domestic kitchen scenario where firewood stoves are common for cooking—the formulation of the brief and design experiment is elaborated in the following sections.

4.10.2 Product Ideation and Concept Generation Experiment - Design Experiment II

The Background:

According to the advisory board on Energy (ABE), around 94.5 per cent of rural households in India depend on non-commercial energy, mainly on firewood and partly on crop residue and dung (Ravindranath & Ramakrishna, 1997). This was also observed during this researcher's field visits to the villages in Maharashtra and Meghalaya. Firewood stoves are commonly used in the kitchen for cooking. It was noted that the local community preferred firewood because there was poor distribution service of LPG gas cylinders, and the often electric supply was poor.

The Design Brief

Ravindranath & Ramakrishna, (1997), in their study, report that smoke emitted from firewood cooking is associated with various health hazards, including respiratory diseases. The poor health of women in rural villages is linked to the type of fuel used and the inefficiency of the cooking devices. In most village households, the lighting and ventilation are very poor. While at home, the women spent the maximum time working in the kitchen, cooking and doing other household chores. There is always smoke accumulation in the kitchen and the integrated living room during cooking, resulting in a smoky environment.

This introductory input, supported with photo images of the typical scenario of a rural domestic firewood kitchen, is provided to the group of participating industrial designers as the design brief. The Designers are asked to study the scenario of this typical village household kitchen and ideate and generate concepts for a PIPV based product solution that can address the issues emanating from cooking using firewood stoves.

Examining the outcomes of the process followed in addressing this real-world scenario formed the basis for the formulation of this design experiment.

Participants in the Design Experiment

An open invitation was sent to groups of professional industrial designers having at least one year of work experience. Six industrial designers agreed to participate in this design ideation experiment. They were split into two groups, with three designers participating in each group. Figure 4.47 shows the schematic flow of design experiment II.

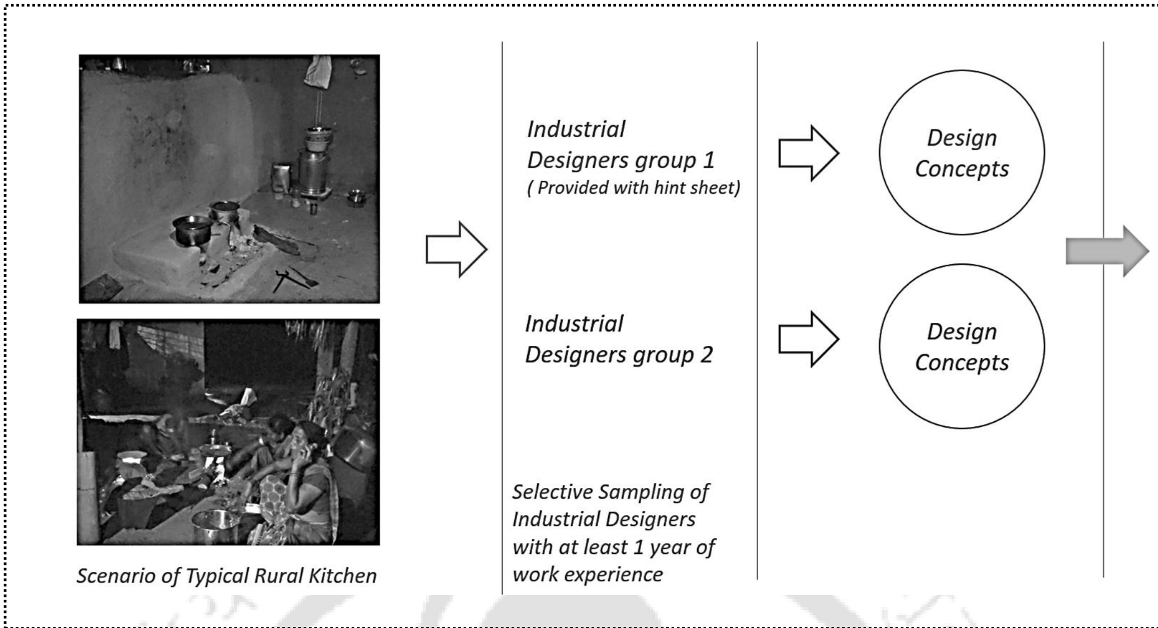


Figure 4.47 schematic flow of design experiment II.

The material provided to the Participants

Both groups were provided with the snaps from the rural firewood cooking scenario as a design brief for concept generation. (Figure 4.48)

Figure 4.48 firewood cooking stoves in the kitchen of rural households

Only one group was provided with a PV hint sheet with two different technical specification sheets that comprised information about two different sizes of solar panels and the corresponding components compatible with them. They could conceptualize ideas using the PV tech hint sheets to generate PIPV based product ideas. The other group was to generate PIPV product ideas following a scenario-based brief without the use of the supporting PV based technical hint sheets. Figure 4.49 shows the PV hint sheet provided to Group 1

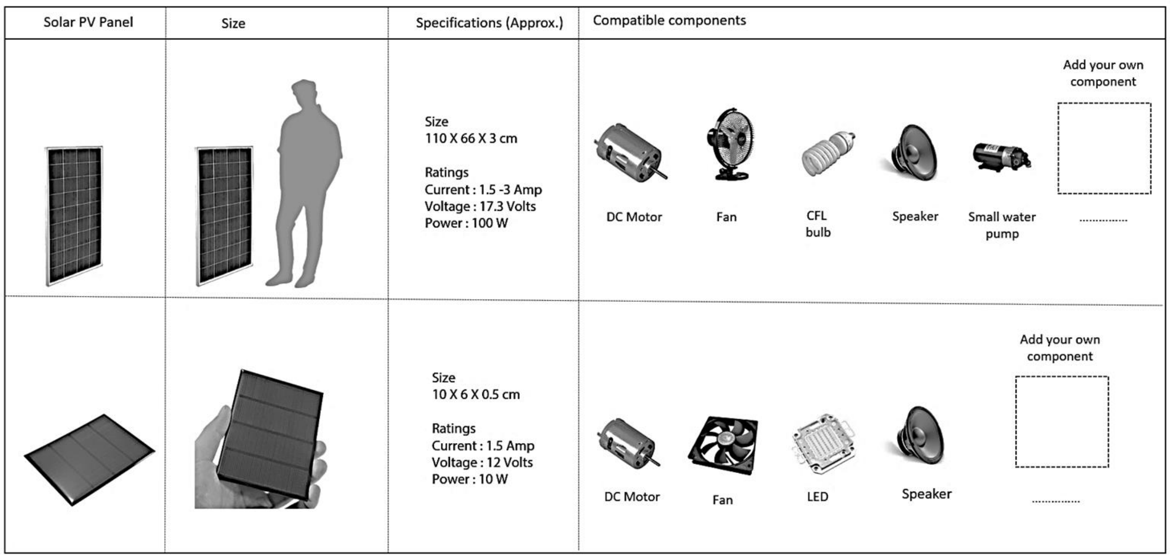


Figure 4.49 PV hint sheet with information on solar PV panels and compatible components provided to Group 1.

As can be seen in the schematic, the PV hint sheet includes two solar panels of different sizes and specifications. Relative images of the PV components are shown with reference to the human scale to give a visual idea of the size of the panel. The corresponding compatible components with the panel are shown in the form of visuals and names. The provision of blank space is kept to the designer groups to add an extra component that they can think of for PIPV concept generation.

4.10.3 Ideation and Concept outcomes: PIPV concept generated during experiment II

The concepts generated during this session were analyzed for technical feasibility and novelty. Out of six concepts generated during the experiment, four were modelled in 3D software and rendered for better visualization. The concepts are described one by one in this section.

Concept 1: Solar PV powered induction roti maker and cooker.

Figure 4.50 shows the concept of the PIPV induction roti maker and cooker. It has a circular solar PV panel on the top of the product, which provides power to the battery integrated into the product. The product includes the induction coil used in conventional cooktops.

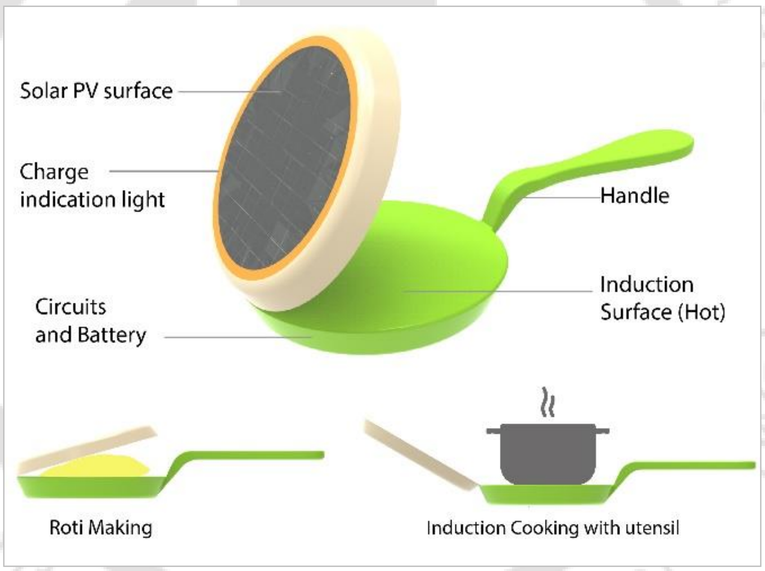


Figure 4.50 PIPV induction roti maker and cooktop.

Assessing the concept, it was felt that currently, the product concept is not feasible because the induction coil needs a considerable amount of power to generate enough heat to achieve the function of cooking. This is not technically met with the size of the panel used in this concept. However, it may be assumed that in the near future, due to technical advancements in PV technology, it may be feasible to generate power with such a small PV panel. So, currently, the concept is marked as a 'future' product.

Concept 2: Solar PV Powered Air blower for firewood cook-stove

Figure 4.51 shows the PIPV air blower for the firewood cook stove. The idea is to power a fan to blow air to enhance the combustion of the burning firewood and reduce the amount of smoke generated during combustion.

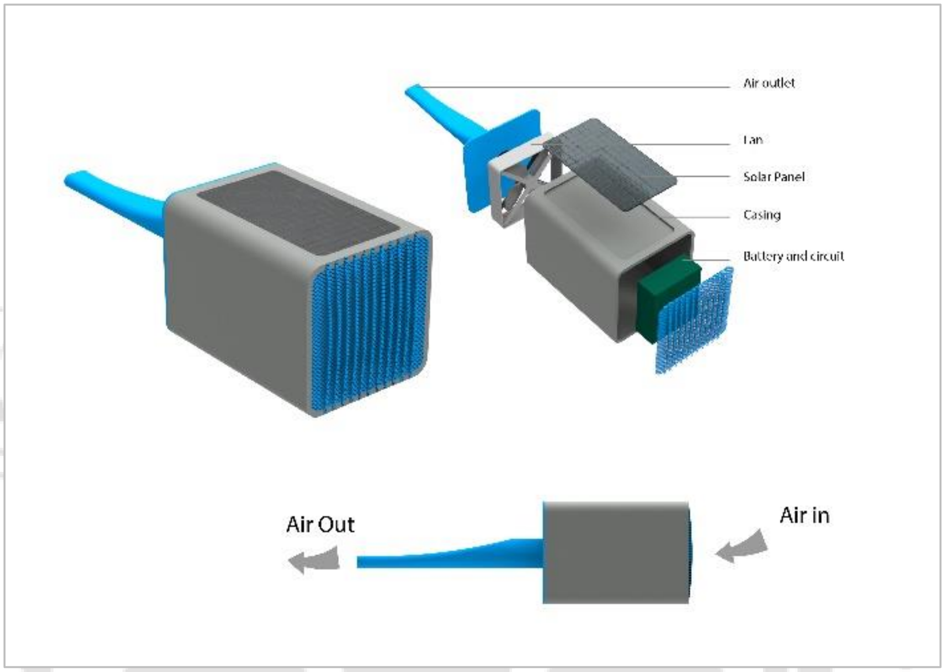


Figure 4.51 PIPV air blower for firewood cookstove

Considering the present status of current PIPV technology, the air-blowing device conceptualized is feasible. The product concept with the selected size of the integrated solar PV panel powers the small battery pack and charging circuits to run the fan for blowing air.

Concept 3: PV powered cooking stand

The concept of a PIPV cooking stand - is a product in which solar cells are mounted on the tripod stand that holds the induction utensil. The stand is kept in sunlight to charge the battery integrated into the stand. During cooking, the utensil kept on the stand gets heated by induction technology integrated into the top portion of the stand. Figure 4.52 shows the concept of the PIPV cooking stand.

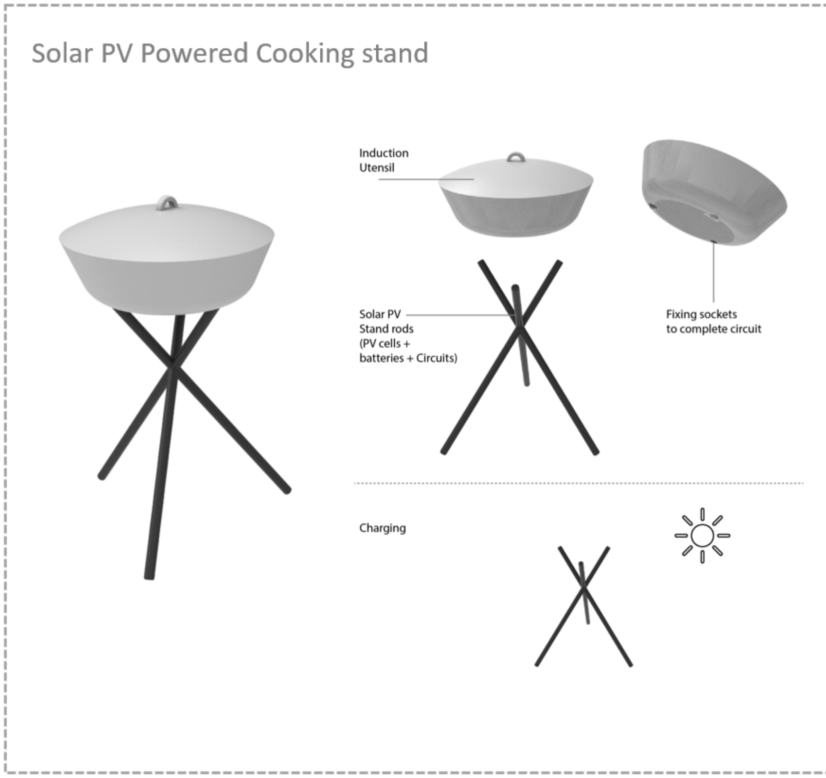


Figure 4.52 PIPV cooking stand for induction cooking utensil

This concept raises the question of the feasibility of mounting PV cells on the surface of a tripod stand and the integration of batteries in the three arms of a tripod. Considering the current technology of PV power generation, the concept is not currently feasible. Further, the induction coil's involvement in the system needs a considerable amount of power, similar to the earlier concept of the PIPV induction roti maker. So, the concept is marked as a ‘future’ product.

<u>Concept 4: PIPV exhaust system for the rural kitchens.</u>

The designer focuses on the issue of smoke accumulation inside the house to generate the concept of a PIPV exhaust system. The bigger solar PV panel and DC exhaust fan are used to perform the desired function of the product. Figure 4.53 shows the concept of a PIPV air exhaust system for the rural kitchen.

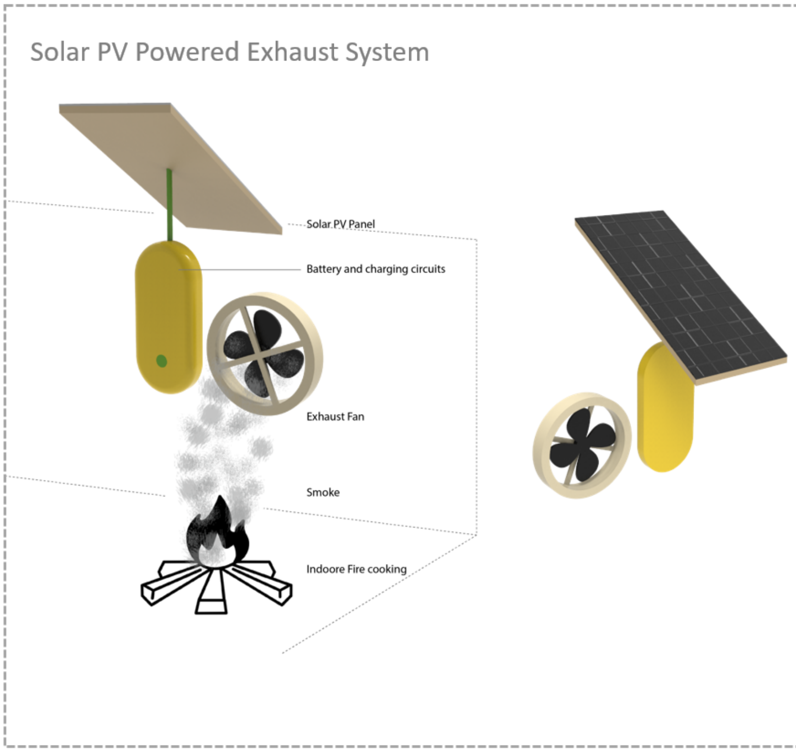


Figure 4.53 PIPV exhaust system for rural kitchen

The concept is generated referring to the given PV hint sheet by this designer. The PV panel and the components selected are compatible, making the proposed system technically feasible. Table 4.2 lists the six concepts generated by the participating industrial designers in experiment II.

Table 4.2 PIPV ideas generated by Industrial Designers in scenario-based design experiments.

Sr. No	Product Name	PV Hint Sheet Provided	Components used	Feasibility Remark
1	Solar PV powered induction roti maker with cooktop	No	-Induction coil, Solar Panel, Battery, Circuits	Future Product
2	Solar PV Powered Air blower for woodfire cookstove	Yes	-DC fan, Battery, Solar panel, Circuits	Feasible

3	Solar PV powered Exhaust system	Yes	- DC fan, Battery, solar panel, circuits.	Feasible
4	Solar PV powered rechargeable Induction Cooking stand	No	-Induction coil/rods, cylindrical batteries, small Solar cells	Future product
5	PV Powered fan with entertainment system (FM Radio)	Yes	DC motor with cam mechanism, FM Radio circuit, PV panel	Feasible
6	PV powered Rice Cooker.	No	Rice cooking utensil with integrated PV panel and electrical Heating mechanism	Future Product.

4.10.4 Observations

As is clearly evident from the table, a pattern consistently emerges of the novelty and feasibility aspects of the ideas generated. Concepts (2,3 and 5) in which the designers had access to PV hint sheets that clarified and informed them of functional and technical aspects of the components resulted in solutions that seemed practical and feasible to produce. While concepts (1,4, and 6) in which they did not have access to the PV hint sheets resulted in novel ideas that seemed driven by the scenario of use but seemed impractical to realize in the present state of technical feasibility due to limitations of the components available. Perhaps in the near future, technology may get directed in these new directions to make them feasible in the future. So instead of rejecting these conceptual ideas, they are retained as 'future' products to aspire and look forward to a later period in time.

The support of the PIPV hint sheet seems to clearly aid and support the designer in directing their conceptualizations to produce feasible ideas. Though the ideas generated by the designers without a PIPV datasheet are novel, they are not technically feasible in the current state of technology. Here technical feasibility was determined by analyzing energy input to the product and energy required to run used components for its functioning. PV hint sheets contained information about solar PV panels with compatible functional components, so the concepts generated using them were feasible and reduced the time the designers spent on the concept generation process. There are fewer chances of the concept being rejected in the next stage of concept development.

This study gives insights into the requirement and possible structure of adopting the feasibility tunnel in the product development process that is adequately supported with usable and interpretable data for Industrial designers while designing PIPV products.

4.11 Chapter Summary

The chapter elaborated on the studies conducted and the different methods adopted to gather information on PIPV products available in the market. As per one of the research aims, it was essential to identify and review the available commercialized PIPV products in the market and innovative attempts in PIPV by users at the grass-root level. These interventions were identified and mapped on a particular mapping structure based on Maslow's hierarchy of needs model. The identification of product intervention directed the plan in conducting an experiment in ideation and interventions in PIPV products conceptualized by industrial designers following an open brief drawn from the product matrix for intervention. These conceptualized product ideas were also mapped to determine which segment of need they addressed, considering the context of rural India. Assessment of product concepts is essential to identify the improvement areas. The spider-web analysis model visualizes and provides an understanding of improvement areas of PIPV product concepts based on the crucial indicators identified from the users associated with rural India’s context. The spider-web analysis model was adopted and validated as a means for concept assessment.

The two design experiments were conducted with industrial designers to study and understand the PIPV product design process and its associated challenges in addressing and strengthening the technical feasibility aspects of the product during the ideation phase. The four sections have undertaken research studies that have directed the product development process, methods and modes of assessment covering the different stages of the design conceptualization and product refinement process in developing PIPV products for the rural context of need.

In the next chapter, we apply this understanding of the proposed process considering the domain of household activities and undertake a case of product development of PIPV air blower equipment for firewood cookstoves. The chapter attempts to validate the proposed process covering stages from product ideation to its realization into a functional working prototype that can be field-tested with users for their feedback.

CHAPTER 5

Ideation to Realization: Transition of PIPV Product Concept

Chapter five covers the journey of the PIPV product concept from the ideation phase to the realization phase. The feasible concept from the design experiment is developed in an actual working prototype of the product and tested with targeted end-users in their living work environment for their feedback. This process gave insights into the challenges and barriers to the realization of PIPV products for rural context during the design and development process.

5.1 Introduction

The previous study described in chapter four identified, reviewed and assessed PIPV product development processes during the fuzzy front-end phase of the development process. It introduced the different methods covering literature review, field studies, direct observations, market review, and approaches to product analysis relevant to the industrial designer for gathering knowledge of the current state of development of PIPV based products. It conducted two design experiments with industrial designers for design ideation and product conceptualization following open-ended and scenario-based approaches. These experimental studies noted that providing Industrial designers with PV hint sheets that extend easily interpretable data about Solar PV panels and compatible components aided the conceptualization of product ideas that are feasible to realize and meet demands of extending to the next stage of product realization. In contrast, those produced without any data seemed less technically feasible considering the current state of solar PV technology.

In this chapter, we focus on understanding the process of transition of the PIPV concept from ideation to realization phase. It will enrich an understanding of the changes through which concepts pass and the barriers and crucial factors that need to be considered for the successful development of PIPV products for the rural context. The chapter describes the various steps adopted for developing the PIPV concept and tries to find an effective and optimal time-saving process for the development of PIPV products.

5.2 Selection of PIPV Product Concept for Development

Input information, including problem definition, the context of the use, the target users and parameters like cost of material etc., influence decisions on the design of the PIPV product during the concept generation phase that can be generated from external Field studies. After the concept generation phase, the product moves to the detail design phase of development, where the input information like functional requirement of the product, specifications of various electronic components, component dimensions and information on electronic components is required. External support in the form of component specifications and information on electronic elements that are part of electronic system design is required. External support in manufacturing infrastructure – machinery, materials, tools, fixtures, etc. are required during the manufacturing phase. Along with these requirements, a database of technical details of hardware, including various sizes and specifications of solar PV panels, aid in the selection of appropriate and compatible solar PV panel for the proper functioning of the product.

Input information and external support required for industrial designers during the different phases of concept development are mapped below in Table 5.1.

Table 5.1 Input information and external support required for industrial designers in various phases of developing the PIPV product concept.

Development Phase	Input Information	External Support
Concept Generation	1. Problem Definition/Design Brief 2. Context of use 3. Target users 4. Limiting parameters like cost, material 5. Form Exploration	1. Field requirements
Detail Design	1. Functional requirement 2. Component specifications 3. Component dimensions 4. Electronics elements	1. Component Specifications 2. Electronics Elements
Development	1. Material Selection 2. Manufacturing process 3. Manufacturing and Assembly	1. Manufacturing possibilities

These prerequisites empower the designer to move from the concept generation phase to product realization.

In meeting the above pre-requisites, the stages to which the product concept undergoes transformation for its realization during the development process involve the following stages:

- Initially, the feasible concept is selected and deconstructed to know the involved components.
- The required components are then collected to know their specifications and functioning.

- The various steps are followed to identify the barriers and requirements for developing PIPV products.
- The involvement of electronic systems in the product is designed and developed with the involvement of technology experts who are active in the field of electronic system design.
- The developed prototype is then tested in an actual user environment to get user feedback on it.
- The developed product is then accessed based on various factors that apply to the rural scenario.

5.2.1 Involvement of Technology experts in electronic system design

The product development process requires teamwork between Industrial Designers and Technologists. The Industrial designer is responsible to conceptualizes and visualising the product from a 'human-centred' end-user perspective. Some of the inputs the Industrial designers seek are sought by enquiring on the following aspects:

- What is the context of use, and who are the target users?
- What function does the product fulfil?
- What components (electronic) are required to fulfil the function of the product?
- What are the specifications of the PV panel?
- The size of components is essential to explore other design parameters like form, material etc.

Figure 5.1 shows the involvement of industrial designers and technology experts in developing the PIPV concept from the design brief.

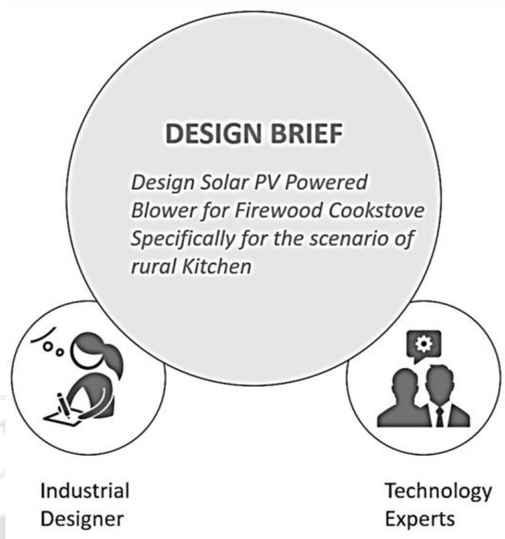


Figure 5.1 Involvement of Industrial designers and technology experts to develop the PIPV concept from a design brief.

Considering the above questions, the technology experts who can contribute with their know-how are identified as part of the development team. With their expertise, they are tasked with developing the path of electronic systems, including defining the technical specifications and a selection of PV panels for the product. The data/instruction extracted from the participating team of industrial designers and technology experts is shared to progress in the development stages of the PIPV product.

5.2.2 Selection of Feasible Concept for Development

The steps adopted for this study are described in the following sub-sections.

The product concept of the PIPV air blower for firewood cook-stove (generated during the scenario-based design experiment) that aims to reduce the smoke generated during the cooking process is selected for further development. As shown in figure 5.2, the product form visualized as a concept has a rectangular cuboidal form. It houses the rigid solar panel on the product body and the other electronic components assembled inside it.

After understanding and recording all technical and dimensional information of the components required to realize the product concept, the form variations can be explored again by the designer keeping these factors in mind. Figure 5.2 shows the 3d model conceptual rendering of the PIPV air blower.

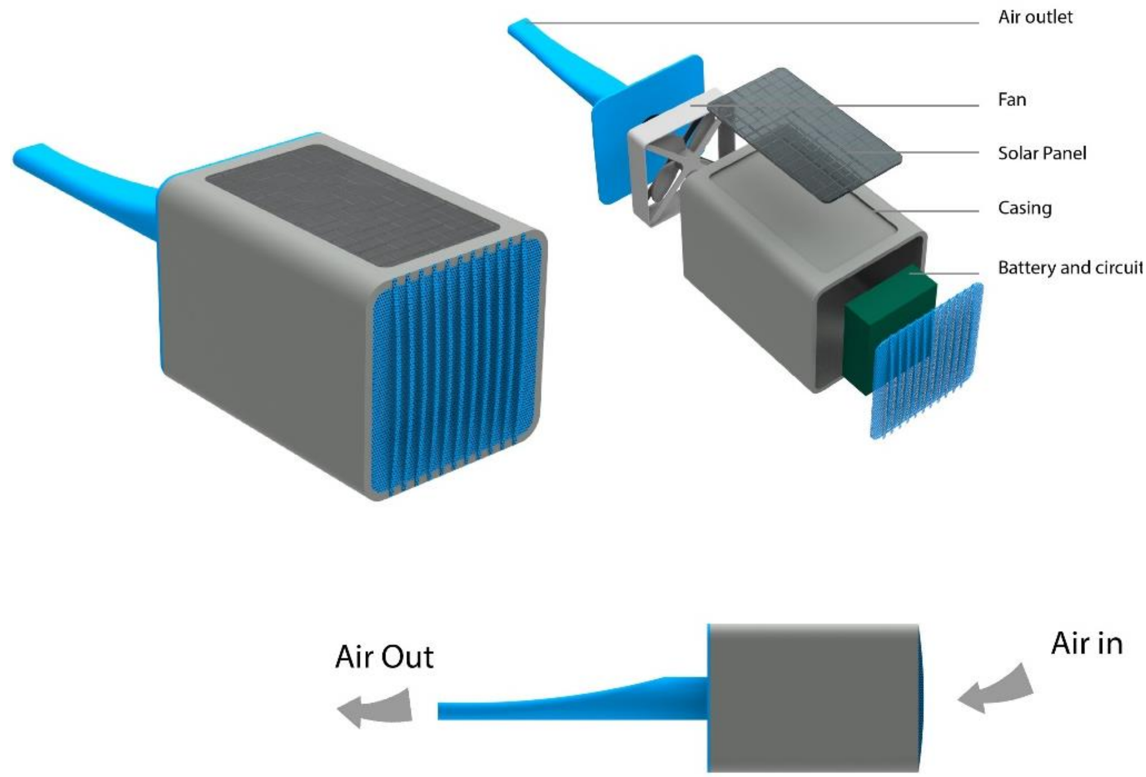


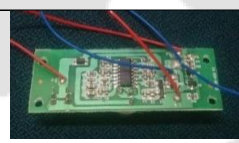
Figure 5.2 Concept of PIPV air blower selected for prototype development.

5.3 Towards Product Realization - From Concept Selection to Technical development of PIPV product

The process flow involved in developing the PIPV air-blower for fire-wood cook-stove underwent the following stages:

The first step of developing the PIPV air blower is to deconstruct the components involved and understand their contribution to its proper functioning. The various components, viz. the fan, DC motor, Solar PV panel, charging circuit, and rechargeable battery, contribute towards meeting the functional requirement of the blower. With their specifications and images, all these components are collected and described in table 5.2.

Table 5.2 Functional components required for developing the PIPV air blower concept.

Sr.	Component	Image	Description
1	Air Blower Dc Motor Plus Fan		DC high rpm motor with a fan attached to the shaft DC motor 3.6W, rated voltage 12 V, Rated current 0.15 - 0.75 A rated speed 9800 Rpm
2	Solar PV Panel		Polycrystalline solar panel 0.55 W
3	Lithium ion Battery		Lithium-ion battery: 3.7 V, 1200 mAh
4	Charging circuit		Charge controller circuit with various components.

Protek Instruments Pvt. Ltd.,[6] in Pune, Maharashtra, a reputed manufacturer of electronic components for solar PV products, was approached to lend technical expertise for this study. Protek instruments have been active in electronic system design for solar photovoltaic products for eight years. They have executed various projects for NGOs,

[6] Protek Instruments Private limited is the company based in Pune. They have manufactured various solar PV lighting solutions and other product solutions. The voluntary participation letter is attached in appendix IV

government and private organizations. During interactions, their founder Mr Akshay Horne confirmed that Solar PIPV product interventions could help solve some of the issues associated with electricity dependence in rural and remote parts of our country. As a part of this study, the researcher visited their manufacturing facility to observe their process of electronic product development. They were agreeable to being the technology experts to participate in the research.

First, a database was built of various sizes of PV panels with the help of identified technology experts in Protek Instruments. This information is used in the next part of the study. Figure 5.3 shows the database of various sizes and specifications of solar PV panels.

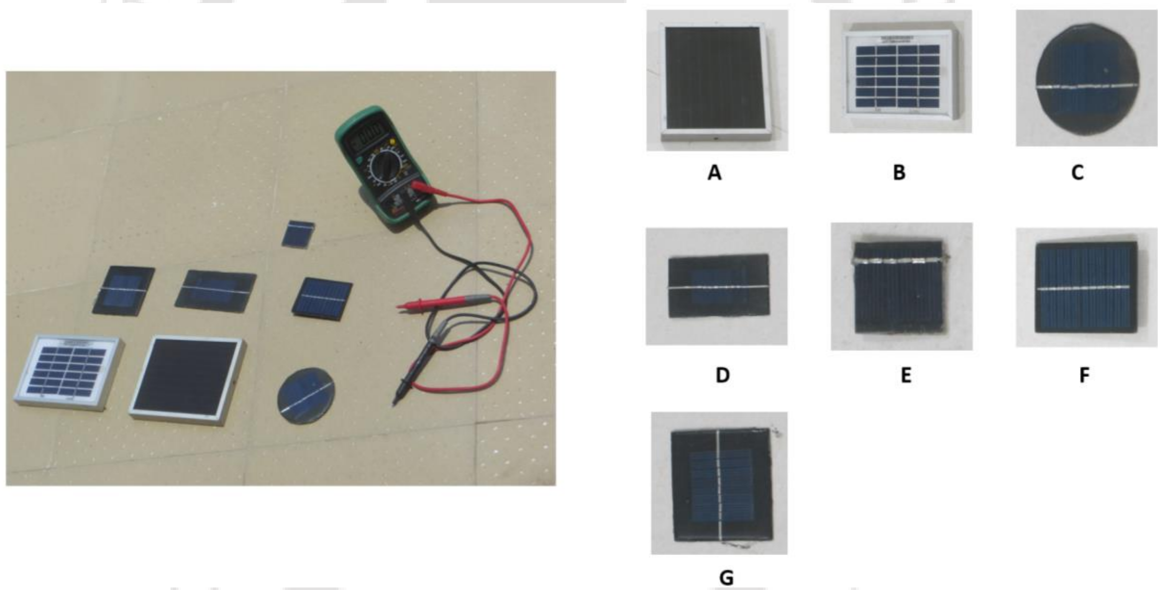


Figure 5.3 Database of Solar PV panels with various sizes and specifications

A total six number of panels were collected from the market. The current-voltage rating of the panel is measured in peak sunlight conditions to estimate the wattage of each panel. Table 6.3 shows the current and voltage rating of collected solar PV panels for the database.

Table 5.3 Current and voltage rating for solar panels collected from the Solar PV panel database

Panel	Dimensions (W X H) cm	Current	Voltage	Watt
A	18 X 11	0.5	4.0	2
B	14 X 11	0.9	2.0	1.8
C	Dia. 6	0.3	2.0	0.6
D	7 X 3	0.46	1.5	0.7
E	6 X 5	0.27	1.5	0.4
F	7 X 4	0.48	1.6	0.75
G	9 X 5	0.54	1.5	0.8

The appropriate components are selected considering the various specifications of solar PV panels collected for the database and other functional components. The electronic system design approach is defined with inputs from consultation with technology experts.

Figure 5.4 shows the steps in selecting various components for the electronic system design of PIPV products.

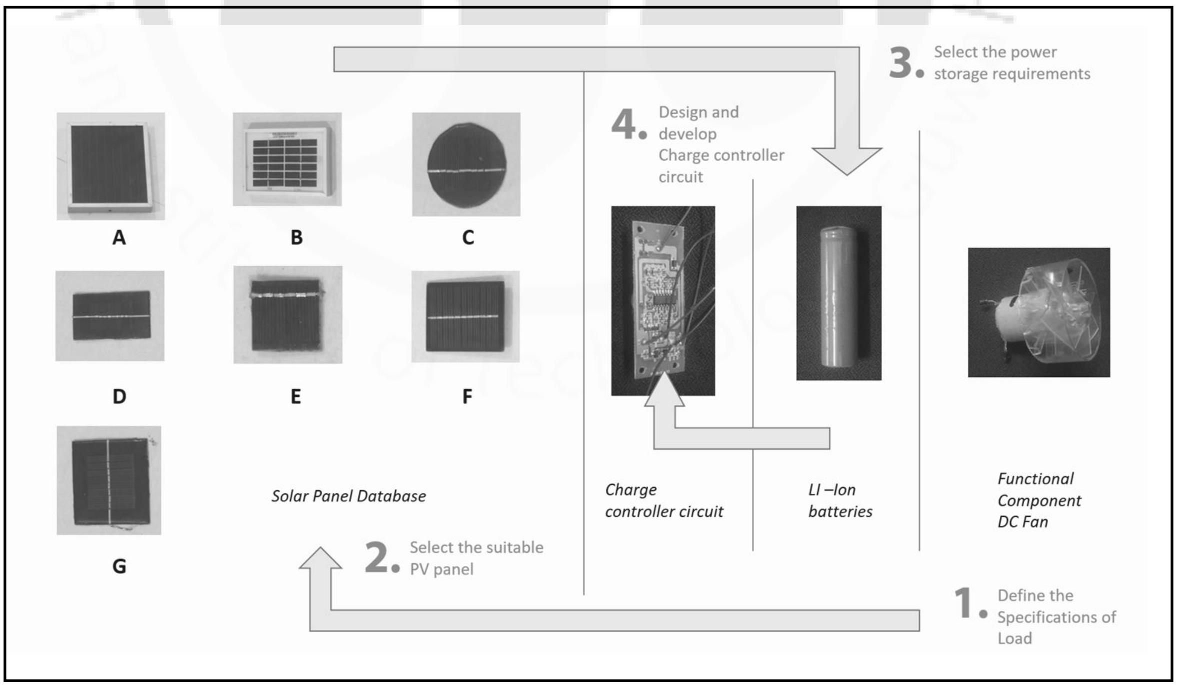


Figure 5.4 step by step approach for electronic system design of PIPV product.

The PIPV product's function needs to be considered in the first step. The load for the primary component driving the function is selected. In the case of the PIPV air blower, it is a DC motor with a fan. The load selection defines the required solar panel to drive that load for a specific time, based on which the solar panel should be selected. The database of various solar panels helps in this regard. In the case of battery-inclusive systems, the battery should be selected based on the system's required working hours and charging time. In the fourth step, the charge control circuit needs to be developed, which coordinates all the selected components for the proper working of the PIPV product. These steps involve the iterations, including checking the current-voltage ratings of various components, checking compatibility with each other, defining the type of power storage requirements, and designing and developing charge controller circuits. Though these iterations are crucial in developing PIPV products, the scope of the study was limited to the factors affecting industrial design it. It is realized that electronic system design is one of the factors which requires specific expertise. It is fulfilled by involving technology experts in the development of the product. This waterfall model is used to describe the approach to the design of electronic systems for PIPV products, which is shown below in figure 5.5

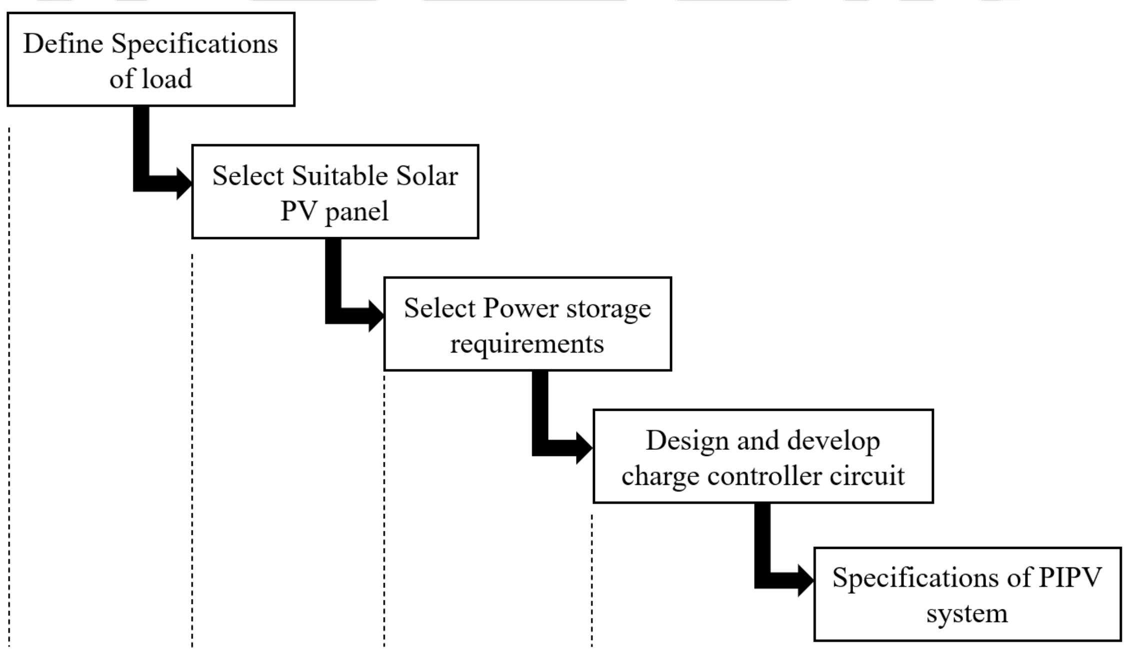


Figure 5.5 A waterfall model for the flow of electronic system design of PIPV product.

The electronic system design yields the component required for the functioning of the PIPV product, including the size and specifications of the solar PV panel. The details are then provided to the industrial designer to refine the concept considering the product's form, usability, and ergonomics.

5.3.1 Refinement of the concept of PIPV air blower

After doing the freehand sketch iterations for the product form, the Industrial designer preferred transferring them into CAD product renderings.

The modelling stages included the initial generation of 3D dimensional renderings of components, including the solar PV panel and the other functional components like battery, Fan and battery charge controller circuit etc. Variations in the layout of these components to meet the functional requirements of air blowing were spatially visualized using these various component layouts. Following this, the product body packaging was finalized around these different component layouts with the battery charge controller circuit inside it. Figure 5.6 shows the steps recorded from the CAD package.

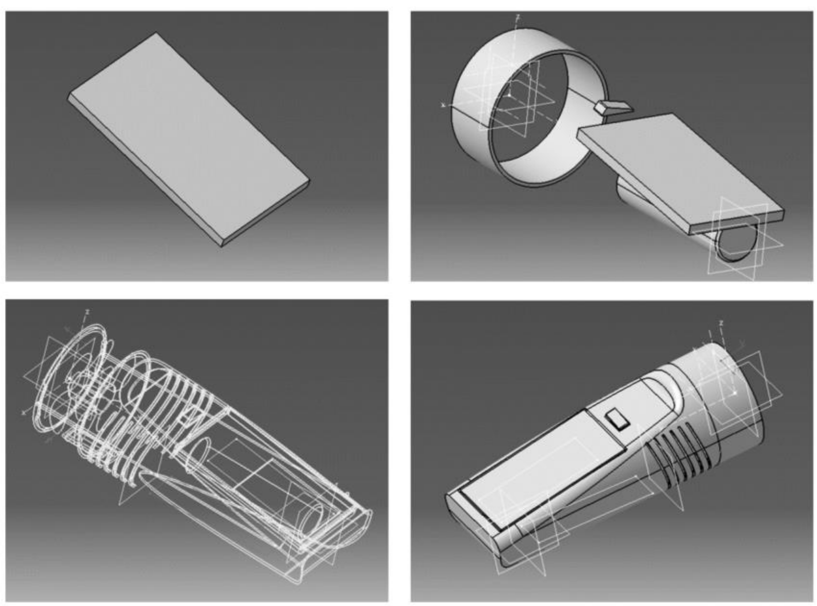


Figure 5.6 Top left- 3D modelling of solar PV panel, Top right – 3D modelling of functional components, Bottom left- the sculpting of product body, Bottom right- Final form of product

CAD and the information about the size of each component give the designer complete freedom when arranging the components. The designer is driven by usability, aesthetics, and functionality considerations while exploring the form.

As seen in the final rendering, the PV panel is mounted on the inclined face of the product body. These considerations are made to improve the functionality of the product. Once the CAD modelling is finalized, the product is digitally rendered to visualize the final design. Considering that blowing air into a burning firewood cookstove for effective combustion to reduce smoke emission is the primary function of the PIPV product developed suitable product name, 'Jhonka' (meaning breeze in the Indian Devanagari language), is selected for the product.

The product concept is presented in the rendering in figure 5.7.

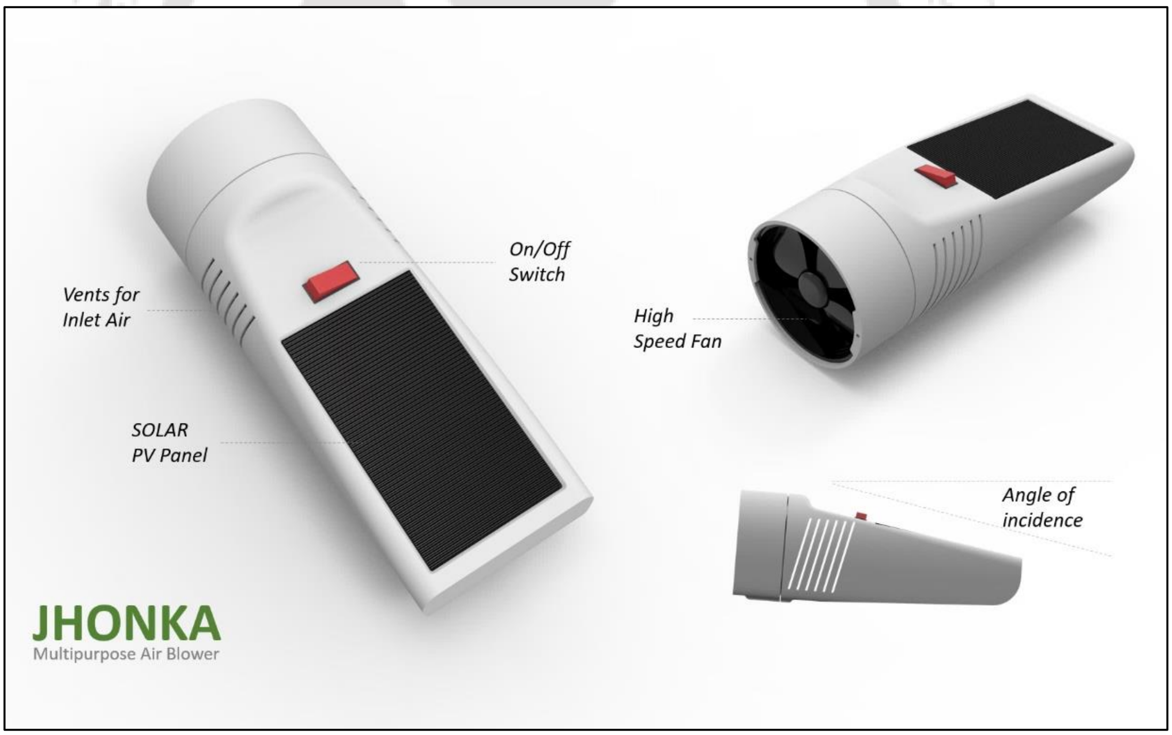


Figure 5.7 The digital render of a refined concept of a PIPV air blower.

A detachable nozzle-type air-blowing pipe was provided as an additional accessory in the front of the product to enable freedom to use the same product for multiple other applications. This is, however, not shown in the above rendering.

5.3.2 Prototyping of PIPV air blower

After electronic system design and finalization of the product form using 3D CAD rendering software, it is taken up for 3-D printing with our technical partner Protek Industries, who was generous to provide their facilities in realizing the first working functional prototype of the product 'Jhonka'

The rapid prototyping technique of 3D printing was opted for product realization considering the short timeline for executing the prototype. As it was the first functional working prototype, 3D printing was selected to manufacture the body of the product. Compared to conventional plastic manufacturing processes like injection moulding, it was a low-cost and time-saving alternative. The electronic system was also designed and developed with the technology experts Protek instrument private limited, who voluntarily participated in the study. The minimal possible deviation is permitted in the rendered concept and the actual prototype to get the correct feedback from the user on the product during the testing phase. The charge controller circuit is developed as per the selected functional components. The circuit manages the battery's charging cycle and the fluctuation in the received power generated by solar PV panels from sunlight due to climate conditions. The charge controller circuit also acts to keep the components safe during the surcharge of the power. The steps adopted in prototyping the product are shown in figure 5.8 and described in detail in this section.

Initially, the outer body of the product is 3d printed as per the data received from the CAD explorations. The selected functional components are then placed and checked for their proper placement inside the body of the product. All the components are then soldered and fixed together inside the body to make the final working prototype of the product. This prototype is tested for its work. Prototype of JHONKA provided 1 hour of working with 5 Hours of charging. Charging time was higher as two Li-ion batteries were used to suit the rating of the high-speed fan.

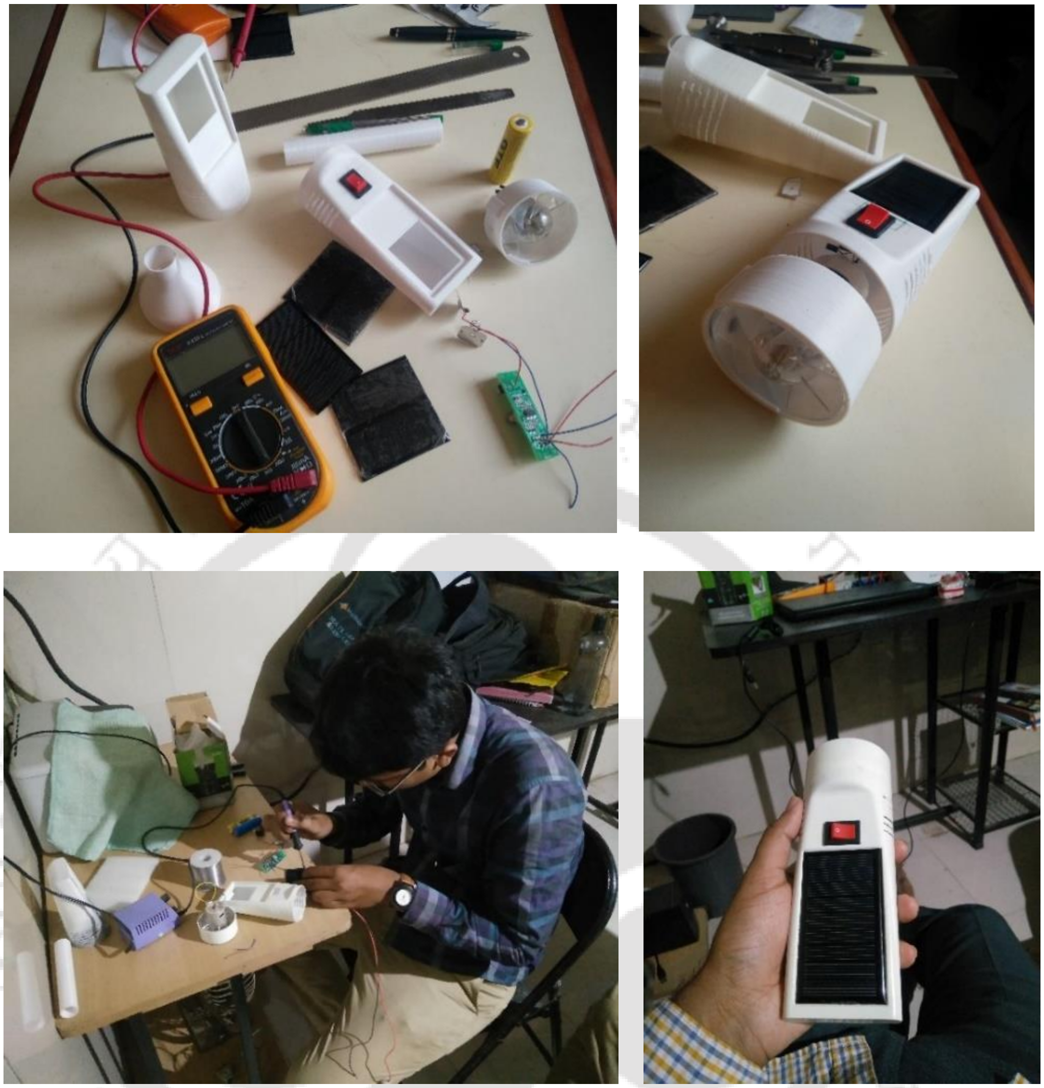


Figure 5.8 Prototyping of PIPV air blower. Top left- function components and 3D printed body of the product, Top right- placement of all the components inside the body, Bottom left – Soldering and fixing of components inside the body of the product, Bottom right- Final working prototype of the product.

The product is designed to solve the smoke-related issue in cooking on firewood cookstoves, specifically in the rural scenario. The developed prototype is tested in the actual user and use environment. User feedback is analyzed on various parameters, which are crucial for the rural scenario.

5.4 Comparison of the PIPV air blower concepts in the Ideation and realisation phase

Figure 5.9 shows the concept of the PIPV air blower in the ideation phase and the same concept prototype developed in the realisation phase.

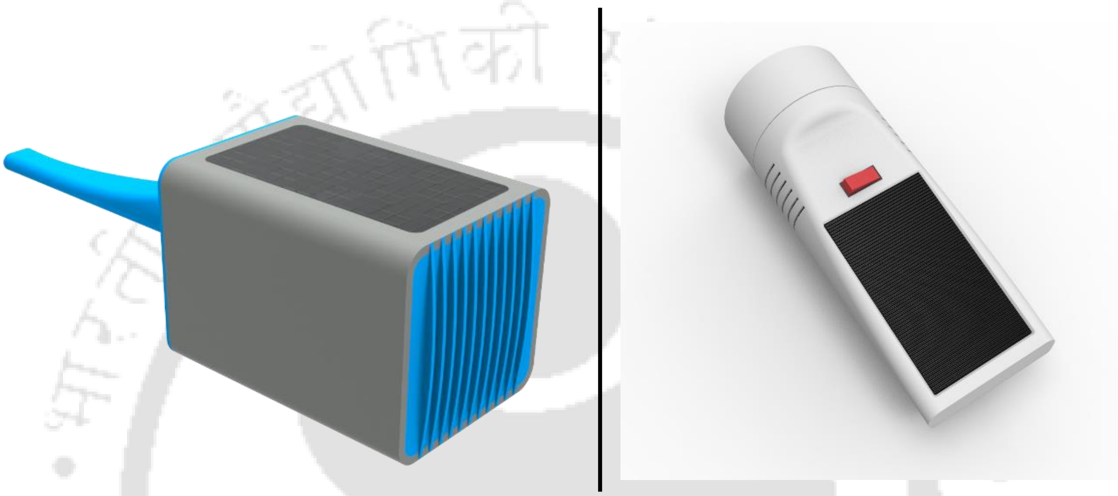


Figure 5.9 Transition of PIPV concept from ideation to realization phase. Left – PIPV air blower concept generated during the ideation phase, Right – same PIPV air blower concept after development into a working prototype.

Show in Figure 5.9 is the two versions that reflect the transition of the first conceptual visualization and its transformation into a working functional prototype of the PIPV based air-blower.

Observations can be made on the improvements of various design parameters. The concept visualized earlier during ideation was very rigid. It is fairly improved during the actual realization of the prototype. This was possible as the industrial designers, in exploring the product's form through sketching and CAD modelling, assisted with information on the electronic system; the size and specifications of all the components were more precisely defined. A comparison of important parameters like form factor, including product aesthetics, Handling, Usability and functionality, was undertaken using Pugh’s matrix method (Solli & Muller, 2016).

Table 5.4 shows the comparison of the concepts of PIPV air blower in the ideation phase and realization phase. Considering the various criteria, the table clearly shows considerable improvement in the product prototype compared to the concept rendering of the product.

- Form factor – refers to the overall form of the product, which defines the outer structure of the product. There is evidently a good improvement observed in the overall product form in the working prototype.

- Handling – is about the ergonomics considerations while using the product. It is evident that the Product prototype is clearly easier and more comfortable to handle in use, considering its compatibility with human hand dimensions.

- Usability – refers to the placement of various components for the effective use of the product. In the PIPV air blower, the product needs to be charged and appropriately kept to expose the PV panel to maximum sunlight.

- Functionality – refers to the ability of the product to perform its desired function. Here there are two associated functions. The primary function is to provide air delivery. The secondary function is to get effectively charged using sunlight. The product prototype shows improved functionality with the angular PV panel directed to the sun more effectively.

Table 5.4 Pugh's matrix analysis of the PIPV air blower concept in the ideation phase and realization phase based on various comparison criteria

Criteria	**PIPV air blower Concepts**	
	Ideation phase	**Realization phase**
form factor	-1	1
Handling	-1	1
Usability	-1	1
Functionality	0	1
Positives	0	4
Negatives	-3	0
Neutral	0	0
Total	**-3**	**4**

Overall, there is considerable improvement in the overall parameters after product prototype development in the realization phase with the contributions and involvement of industrial designers and technology experts in the development phase. It justifies the requirement for external support in the design and development of PIPV products.

The working product developed is then taken into the field and tested with the user to get their feedback and critically analyze it on various factors associated with actual product use in the living environment of rural context. The following section describes concept analysis based on user feedback.

5.5 Testing with Users

The developed prototype was field-tested among women when the researcher visited their villagers near the Nashik district in Maharashtra. Two households in the village were given the working prototype to use while cooking using their wood-fired cookstove. Figure 5.10 shows the testing of the prototype in the field

Figure 5.10 Testing of the prototype in an actual scenario with target users.

After receiving the feedback from the users, the following observations were made:

- The product was designed and developed as an air blower for use with firewood cooking; it is observed that users used it with other activities which need the same kind of function. Users used this product with a water heater which works on the heat produced from firewood burning.
- It was found that the Product performance was not as per expectations as the time taken for charging was considerable lengthy. At the same time, the air delivered from the fan was comparatively low.
- The product was provided only with the function of air blowing. After use for a specific time, users had expectations that it could be used for functions like torchlight, FM radio, mobile charging etc.

The product was then analysed using the spiderweb assessment model to know the lagging factors. Figure 5.11 shows the spider web analysis representation of the product.

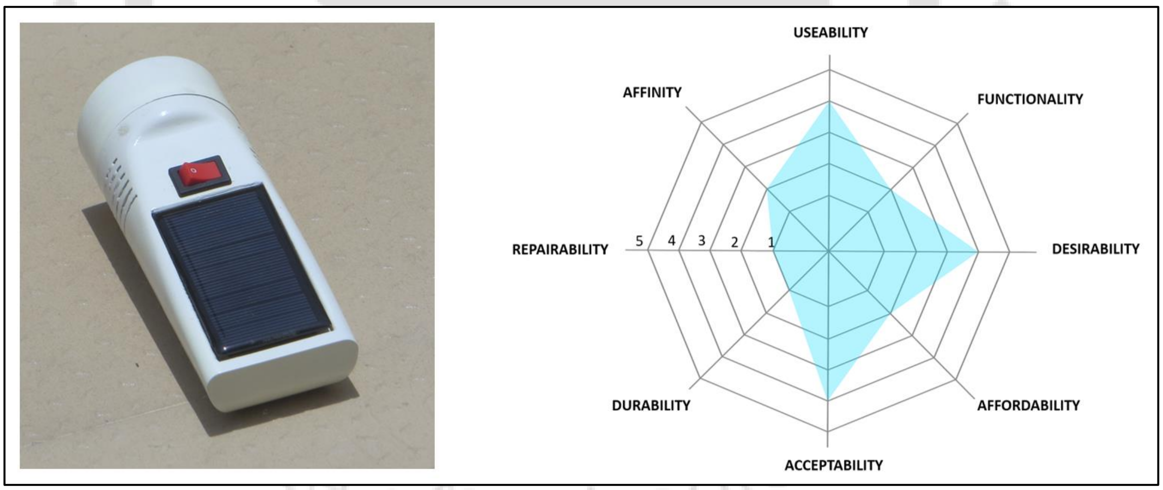


Figure 5.11 Spiderweb assessment of developed PIPV concept based on user feedback.

From the spiderweb analysis, it is observed that the product lags in the aspects of Repairability, durability also poses comparatively low affinity, affordability and functionality. Product repairability was an issue as users were not sure about the maintenance and repair of the product. As the product was manufactured using 3D printing of PLA material, the product's durability was in doubt. Users gave feedback that they expected multifunctional products in this price range; that is why the affordability and functionality were in doubt. However, the product was acceptable, desirable and useable for the users. It depicts room for improvement of the PIPV air blower based on user feedback. The identified factors for improving the PIPV product must be relooked to make it usable and acceptable to its actual end-users.

5.6 Observations and Findings

During the development of the PIPV product, it passed through three phases: product design, product execution and product testing. During these studies, it was realized that three stakeholders are associated with these three phases. These stakeholders are Designers, Technology enablers and product users, respectively. Figure 5.12 shows the phases involved in the transition of the PIPV product from ideation to realization and the associated stakeholders with each phase.

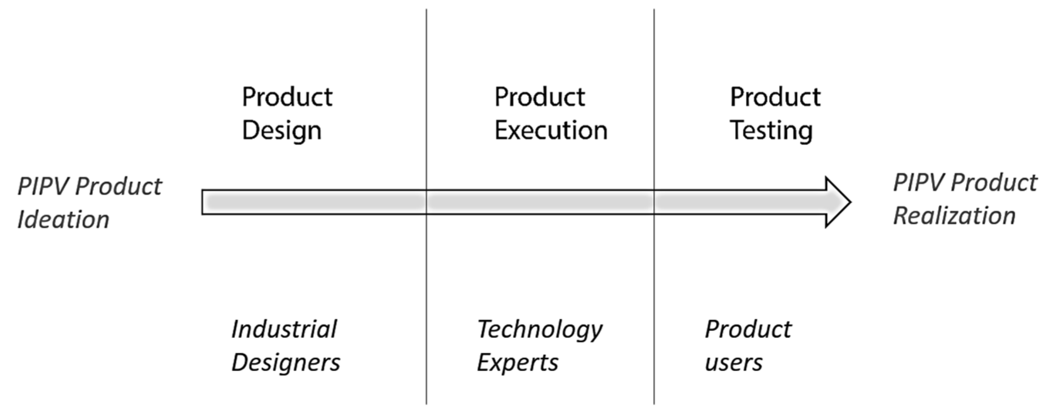


Figure 5.12 Phases of PIPV product development and associated stakeholders

In the product conceptualization phase of PIPV product development, industrial designers work on a specific problem to do the iterations to create PIPV design solutions. A conceptualization has to factor in various functional and structural elements, including electronic systems that enable the product to function. When the product concept enters the execution phase, the electronic system needs to be defined. This involves the technical selection of the right solar PV panel to suit the system's functional requirements. The execution process phase requires the engagement of technology experts who can contribute to the technical aspects required for product realization. Technology experts are the enablers who make the concept work for its function. Once the product is technically developed and its form finalized through this teamwork of experts, it is taken up for prototyping. The first set of functionally working prototypes goes into its testing phase undertaken with the targeted end-users to have their feedback on the product use. The product testing in the field leads to the improvement of the product from the perspective of users. In this process, the product passes through multiple iterations to ensure the possibility of acceptance of the product among its target users.

It is evident that during these different stages of product realization, there should be an active feedback system between the different identified product development phases and the corresponding stakeholders involved for the success of the PIPV product designed for the rural scenario. This system will help reduce the product's lead time to market and increase the rate of success with target users. Figure 5.13 shows the active feedback system model between the three phases of PIPV product development.

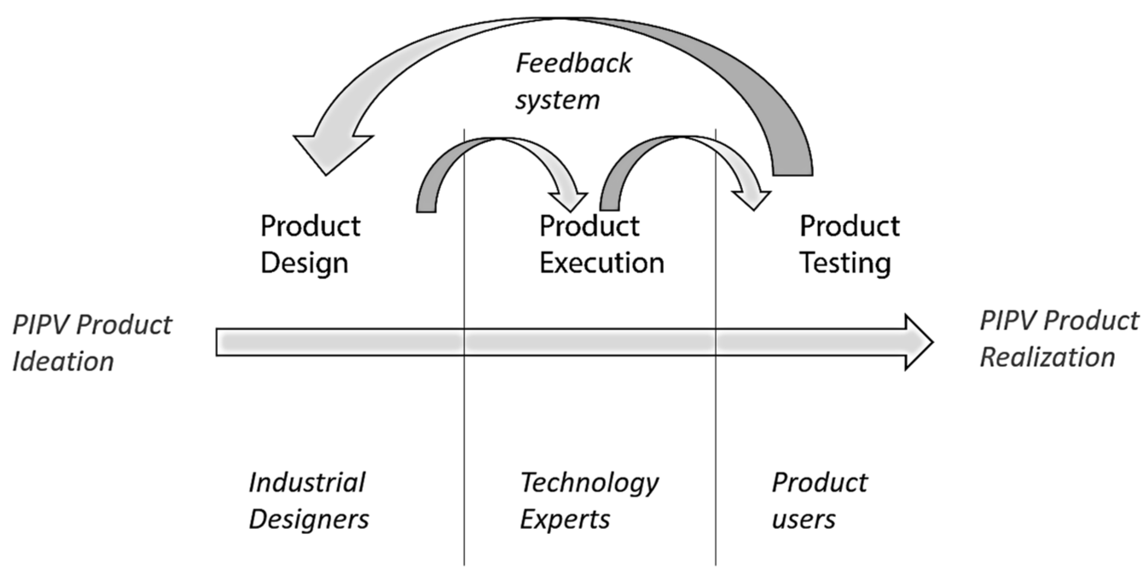


Figure 5.13 Active feedback system between different phases of PIPV product development.

Here product users are the problem owners. Designers solve these problems to create design solutions through PIPV product designs. The design briefs framed from the realization of crucial problems associated with the lifestyle of people staying in rural places will lead designers to act on the actual requirements of users. It will create the PIPV solutions that will address the physiological and safety level of needs crucial to address in the scenario of the rural context of use. PIPV product concepts can be developed within the contextually appropriate parameters and suitable in India's rural environment to ensure their success and reduce the lead-time of development to market.

5.7 PIPV Product Concept Design Sandbox for Rural India

The innovation sandbox model proposed by C.K. Prahlad in his study on 'Bottom of Pyramid as a Source of Breakthrough Innovations' referred to earlier in the Literature review chapter seems appropriate and can be adopted and refined to suit the PIPV product conceptualization in the context of Rural India. The sandbox is framed based on the attributes identified from the field studies conducted in this research. Figure 5.14 shows the sandbox model for the PIPV concept development for rural users.

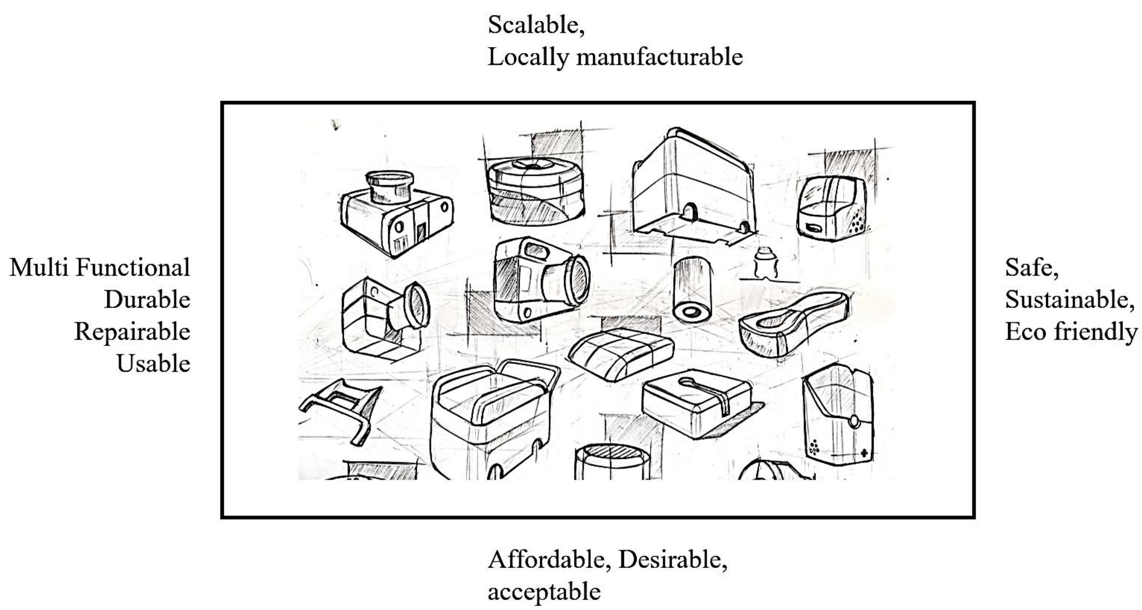


Figure 5.14 The sandbox of the PIPV concept development for use in the context of rural India.

For any PIPV product concept to be effective in the environments of rural and remote areas, the essential factors are: multi-functionality – multiple functions linked with the primary function of the product; durability – the ability of the product to sustain the harsh conditions; Repairability – the ability of a product to get the repair at local resource; and Usability – the ability of a product to get used easily by its user. In rural India, the product can be accepted by users if it is affordable, desirable - it must-have qualities that users desire, and acceptable - it should not have any attributes that could cause negative interference with the culture and community so that it can get accepted by the users and specific communities. The conceptualized solution should be scalable as it can benefit both the users and its creators; also, the manufacturing of PIPV product solutions in locally available resources helps create the product's ecosystem and improves the awareness and other attributes like availability and repairability of the product concept. On the fourth boundary of the sandbox, the safety of the product, its sustainability and eco-friendliness are marked considering the conservation of the local environment significantly associated with the Indian rural ecosystem. The generation of the PIPV concept considering the boundaries of the defined sandbox will improve the success and acceptance with actual users, primarily the people staying in rural and remote places of India.

5.8 Chapter Summary

This chapter describes the PIPV concept's transition from its ideation phase to the realization phase. This study aimed to understand the requirements for developing the PIPV product from scratch. Various requirements in terms of input information and external support required in different development phases are identified. During this study, insights were gathered about improving the PIPV concept during its development and identified the need for technology experts to assist the industrial designers in the product realization process.

The concept of the PIPV air blower in its ideation stage was taken up for its realization into a working functional prototype. The phases of its transformation are analyzed to check the improvement in its form factor, handling, usability, and functioning. The concept is significantly improved from ideation to implementation on all the above parameters. The prototype developed using 3D additive printing technology is then field-tested with actual users for their feedback. From the insights gained in this study, it is evident that there is a need for an active feedback system between associated stakeholders. A system can be proposed to bring Industrial designers, technology experts, and product users on one common platform to develop successful PIPV products. The proposed sandbox model for rural context is framed to design and develop the PIPV concept within boundaries to ensure its success and acceptance by users. The findings from this chapter contribute to the research inquiries related to the execution and testing of the PIPV product concept for rural use.

CHAPTER 6

Approach for the Development of PIPV Product in the Context of Rural India – Application of Findings

Based on the findings, the step-by-step approach for the industrial design of PIPV products in the context of rural India is proposed. The proposed approach is validated through its application for the development of a PIPV insecticide sprayer for agricultural applications. This chapter describes the development process of the PIPV product concept adopting the proposed approach.

6.1 Introduction

In Chapter Four of this thesis, insights for opportunities for the intervention of PIPV products in the rural scenario were identified by mapping existing PIPV based products available commercially and analysis of innovative PIPV product interventions at the grass-root levels and design experiments undertaken with practising industrial designers. As part of the design development process, the study in chapter Five explored the challenges of translating conceptual product ideas into tangible, feasible product solutions that can be realized into working and functional product solutions.

The finding from these studies envisages the need for outlining a systematic step-by-step approach for the Industrial design and development of PIPV product concepts considering the context of rural India. This approach is elaborated and validated through the case of product development of PIPV product design intervention for insecticide spraying in agricultural fields. This chapter describes the design, development and testing process of this PIPV product based on the proposed approach.

6.2 Need for a Specific approach for Industrial Design of PIPV products in the context of Rural India

Based on the findings from the earlier studies involved in the research, the three phases of PIPV product development are identified with associated stakeholders. When the PIPV product transforms from its ideation to realization phase, it goes through the product design, execution, and testing phases. These three phases are associated with three different stakeholders or the owners of that particular phase. Industrial designers generate various product concepts based on the identified problem. Electronics and solar PV technology are involved in the product execution. Technology experts contribute to configuring the electronic system required to make a product function effectively. Based on the contributions of the team of industrial designers and the Technology expert, the product is realized into a functioning prototype; this prototype undergoes the testing phase, where it is evaluated by the targeted end-user whose feedback is taken for its use. These phases pose some information that ultimately affects the product's design decisions. These design decisions reflect the success and final acceptance of the product by its users. The steps are defined based on three major factors: the stages of the design process, the steps to take during each stage of design, and the respective outcomes of each step. Specific input information is required in the concept design phase, system level - detail design phase, and testing refinement phase. This information acts as a feed for the industrial designers to generate PIPV product concepts. The involvement of solar PV panel and related electronic systems in the product creates dependability of designers on technology enablers. A developed product's acceptance by users is determined by whether it meets the actual user requirements. The step-by-step approach is proposed to streamline all these design phases, take the respective steps, and manage and utilize the input information.

6.3 Step-by-step approach for Industrial Design of PIPV products

The steps proposed in the approach are identified from the gathered information from the research studies. The outcomes from these stages contribute to the respective phases of the design process. Figure 6.1 shows this step-by-step approach

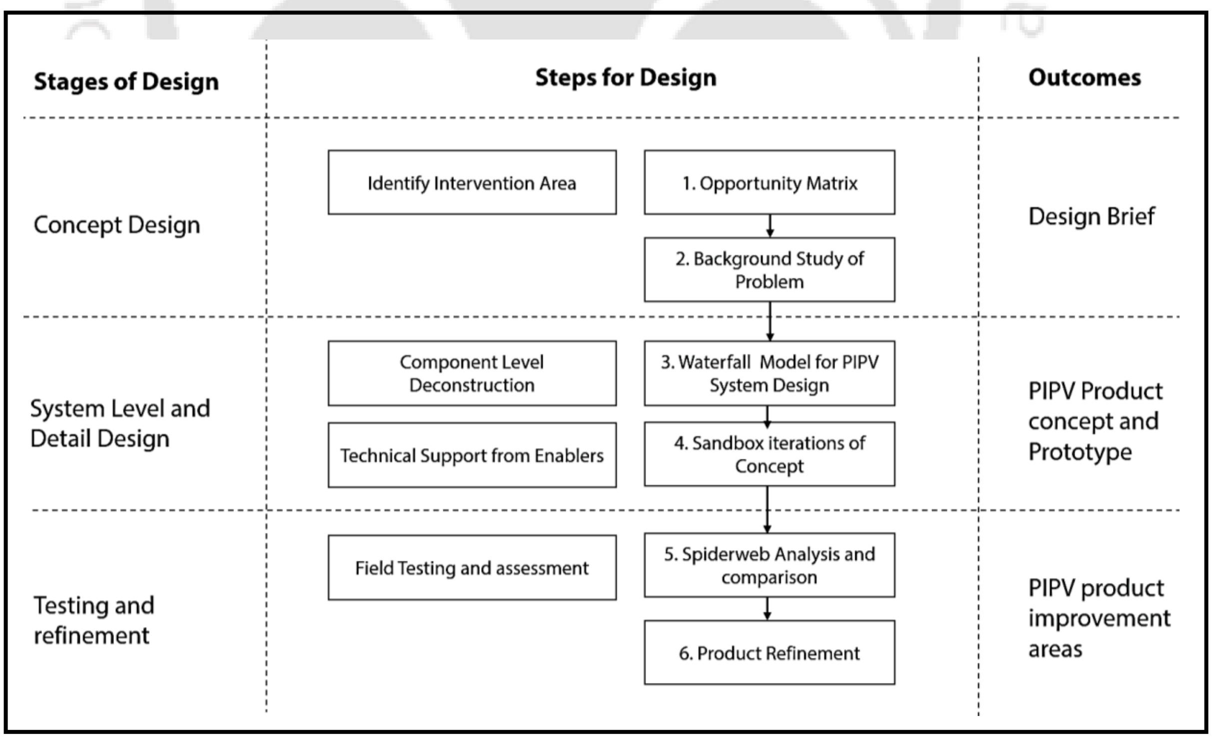


Figure 6.1 Step-by-step approach for Industrial Design of PIPV products

- The left column shows the major stages of the design process involving Concept Design, System-level – Detail Design phase, and the Testing – Refinement phase of the design process.
- The middle column includes the actionable steps for the design of PIPV products
- The right column shows the respective outcome from those steps.

Details description of these stages is elaborated below:

Concept Design stage – During the concept design stage, identifying the intervention area is essential based on which the background information about the problem can be collected. Step 1 and step 2 are defined to identify the intervention area and collect background information on identified problems. These steps yield the design brief, which can be addressed extensively to create respective PIPV product concept solutions.

System-level and detail design stage – PIPV product function is governed by the solar PV panel and electronic system associated with it. The system-level design and detail design stage involves the component-level deconstruction of the system to know the parameters like shape, dimensions and ratings of various components. Solar PV electronic systems should be designed by adopting the steps defined in the earlier study. The concept generation step should be followed by using a sandbox which is defined considering the boundaries catering to the requirements of target users. These steps yield the PIPV product concept and its prototype.

Testing and Refinement stage – Field testing and assessment of the PIPV product concept using spiderweb assessment give the improvement factors and required refinements for the PIPV concept. These inputs are based on actual users of the product and define the acceptance and possibility of success of the proposed solution.

In rural India, the proposed flow can be adopted in steps to design PIPV products.

Step 1. Identify the intervention area – The opportunity matrix gives the direction to choose an opportunity area for concept intervention.

Step 2. Analysis and background study of identified intervention area – Field studies and in-depth understanding of the problem give insight into the required solution.

Step 3. Component level deconstruction of concept and electronic system design – for exploring a concept, the exact information about solar PV panels and associated electronic systems is required, which can be gathered through this step.

Step 4. Concept iterations in the PIPV sandbox – the framework for the concept iterations includes the boundaries defined considering the requirements of the users from rural India. The use of a sandbox for PIPV concept iteration ensures the required attributes of the concept to some extent.

Step 5. Spider-web analysis and comparison of concept – For testing and evaluation of the PIPV product concept, it is essential to evaluate it based on user requirements. The Spider-web analysis method helps visualize the improvement factors for the proposed concept based on user feedback.

Step 6. Refinement of concept – based on the feedback received from the users, the concept can be refined by considering the improvement factors identified during its evaluation.

6.4 Application of proposed approach: Development of PIPV insecticide/fertilizer sprayer for agricultural use.

To validate the proposed approach for designing PIPV products in rural settings, it was applied to the development of PIPV product using the design steps outlined above. The opportunity matrix of the intervention area of agricultural insecticide spraying activity on farms is considered. This section describes the steps followed and the development process of the PIPV insecticide sprayer for agricultural use.

Step 1. Identify the Intervention Area:

From the opportunity matrix, the intervention area of Insecticide spraying of farming process needs in the agriculture domain is selected. During the field visits to the villages of Maharashtra, this activity was closely observed. Also, as this area was accessible for interventions and testing with target users, it was undertaken to study and apply the proposed design approach.

Figure 6.2 shows the opportunity matrix and identified area for the intervention of the PIPV concept – insecticide spraying activity from farming process needs from the agriculture domain. This insecticide spaying activity is then explored to gather relevant information to explore related PIPV concepts.

	Requirements	Sub Activities and requirements					
Agriculture	Irrigation	Water Pumping	Drip Irrigation	Distribution	Lighting		
	Farming Process needs	Land Preparations	Insecticide Spraying	Crop protection	Equipment		
	Harvesting	Plucking tools	Collection devices				
	Post harvesting needs	Separation aids	Drying	Storage Needs	Protection		
	Transportation	Packaging	Carting	Movement needs			
	Banking	Applications	Withdrawals	Teller Machines	Lighting		
Education	Lighting	Indoor Lighting	Outdoor lighting				
	Smart Classroom	Projectors	Computer systems	Equipment	Sound systems		
	Drinking Water	Water purifiers	Dispensers				
	Supportive aids	Libraries	Community learning				
Healthcare	Lighting	Indoor Lighting	Special Needs	Hand equipment			
	Sterilization needs	Equipment	Tools	Sanitation			
	Transportation	Emergency needs					
	Awareness	Advertising	Awareness campaigns				
	Medical Aids	First aid kits	Equipment	Support systems			
Household	Cooking	Stoves	Lighting	Appliances			
	Water heating	Bathing	Cooking needs				
	Water purification	Drinking water	Cooking				
	Entertainment	Weather forecast	Awareness	Social life			
	Refrigeration	Food storage	Air conditioning				
	Lighting	Indoor lighting	Outdoor lighting	Emergency lights			
	Employment	Setups	Equipment	Support systems			

Figure 6.2 Identification of intervention area from the opportunity matrix.

Step 2. Analysis and background study of identified intervention area:

The activity of agricultural insecticide spraying is observed in the actual scenario. A study visit was conducted to Pimplagaon Konzira and Sukewdi villages from Sangamner tehsil and Ahmednagar district of Maharashtra. From the discussion with local farmers, the agricultural spraying process is observed by taking inputs about the entire process.

The agriculture spraying process is divided into multiple tasks, which are listed below

1. Preparing the mixture - This is the very first step in which farmers prepare a mixture of insecticides as indicated
2. Pouring the mixture – the mixture is poured into a spray pump as per spraying needs.
3. Spraying - the farmer has to move through farmland to spray the prepared mixture on the crop. For this, various types of pumping equipment are available. Some of the pumps are motorized, while others are manually operated.
4. Repeat - if the pump tank capacity is small, the farmer needs to refill it to repeat the process.

There are three basic types of pumping systems

A. Manual pumping spray
B. Battery-operated pumping spray
C. Motorized (Engine operated pumping spray)

Farmers use motorized pumping units for large farm sectors as it has a large tank capacity, which is placed at one location and spraying is done through a long pipe circulated through the crops. Figure 6.3 and figure 6.4 show the insecticide spraying on small crops like onion and big crops like pomegranate.

Figure 6.3 Spraying of insecticide to small crops (Onion) by motorized spraying system

Figure 6.4 The motorized spraying system is used to spray insecticide on big crops (pomegranates).

Farmer's affordability is the primary factor that affects their farming process. As stated earlier in this study, most farmers have small sectors of land and low-income levels. They cannot afford expensive and large systems for their farming needs. The process shown in the above images is convenient for extensive farmlands, but it is associated with many parallel drawbacks. Some of them are associated with high capital and operation cost; they need more human resources for their operation; It offers little flexibility of spraying as someone continuously needs to hold the feed pipe. Another alternative to this motorized system is a backpack type of spraying equipment that can be manual or battery operated. These products are helpful for small-scale and economical spraying of farmland. The backpack-type spraying systems are associated with a few limitations; some come with limited tank capacity, which requires refilling after some time. It involves the repetitive task of making an insecticide mixture. Also, the user needs to carry the heavy weight on the back while spraying, which is a tedious task. Figure 6.5 shows the backpack type of manual and battery-operated agricultural sprayer. The manual spray pump comes with a hand-held lever to pump and spray liquid.

Figure 6.5 Left - Backpack type manually operated spray pump, Right **-** Backpack type battery operated spray pump

These systems have advantages and disadvantages listed below in Table 6.1. Due to their associated advantages, such as low cost, individual handling, and accessibility to every corner of the farm, battery-powered backpack spraying equipment is increasingly popular among farmers.

Table 6.1 pros and cons of motorized and backpack-type agricultural spraying systems

Motorized Spraying system	
Cons	Pros
High Initial Cost More workforce requirement High Maintenance Involved Fuel cost Less Accessibility	High Efficiency Less refilling No-load on back
Backpack Type Spraying system	
Cons	Pros
Heavy Load on back Repetitive Refilling Limited tank capacity Battery capacity Stress on hands	Comparatively low cost Individual Handling Accessibility Zero operation cost

The process of spraying by backpack-type sprayer is studied to understand some facts and the associated inputs from users. The input information collected from the field is elaborated on below. Figure 6.6 shows the large farm area being sprayed using a backpack-type sprayer.

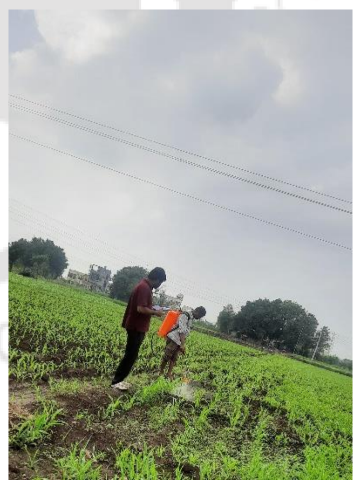
Figure 6.6 large farm area being sprayed using backpack type battery operated spraying equipment.

The following inputs are collected from direct user observation and interviews with the farmers: Fourteen to sixteen tanks of the insecticide mixture are required for one acre of land. Considering this requirement, the user must refill the tank 12 – 14 times as per the crop density. Table 6.2 shows some facts and figures observed during this study.

Table 6.2 Details of the backpack-type battery-operated spraying equipment and spraying activity.

Sr.	Head	Details
1	Tanks required for 1 acre of land	14 – 16 Numbers
2	Tank Capacity	16 Liters
3	Pump Cost (Single battery operated)	Rs. 3200 - 3500
4	Single battery capacity	10 – 12 tanks
5	Time to spray 1 acre field	4 – 6 hours
6	Distance travelled by user while spraying 1-acre farmland	5 – 6 Kms

Table 6.3 Some of the issues associated with these battery-operated backpack types of spray pumps.

 **Refilling** – To complete the one acre of the land user has to refill the tank around 12 to 14 times. This activity involves making the insecticide/fertilizer mixture with water (16 litres) as per the required proportion. Preparing a mixture for every time is a tedious task.	 **Lifting on the back** – user has to lift the spraying equipment on his back. The total weight of the product is around 22 – 26 kg. This heavy lifting is complex, and they have to take some support or adjust their posture to ease this activity. Many times, this results in cramps and pain in back
	
Repetitive – the task of spraying is repetitive. The user has to move in multiple directions to cover the entire field. The total distance covered while spraying one acre is around 5 to 6 kilometres.	**Limited battery** – Battery capacity is limited to spraying 12 to 14 tanks. If the battery is drained, it is not possible to charge it due to the unavailability of an electricity source in a farm field. User has to travel to his home to charge the battery

Product study and comparison – As a part of this step, the various products available in the market are studied to know parameters like cost, capacity, and weight. Table 6.4 shows these parameters. These products are compared based on Pugh's matrix to get the overall rating of the available products based on user feedback.

Table 6.4 Cost, weight and capacity of the various backpack products.

Sr. No.	Product	Cost (Rs.)	Weight (Kg)	Tank capacity (L)	Lifting weight (kg)
1	Manually operated spray pump	2000	4.5	16	20.5
2	Battery-operated spray pump	3100	6.8	16	22.8
3	Battery Plus Manually operated spray pump	4200	7.4	16	23.4
4	The motorised engine-operated spray pump	8000	8.3	20	**28.3**
5	Solar-powered spray pump	5000	7	16	**23**

From the above table, the total lifting weight of the product can be compared. Manually operated spray pumps are comparatively lighter and available at a low cost, but they are associated with a tedious manual operation. This creates difficulty in its use. Battery-operated and solar-powered spray pumps are nearly the same in weight but are comparatively costly. Most pump sets are available with a 16-litre tank capacity except the engine-operated pump, which has 20 litre of tank capacity. This information is used to conduct a Pugh matrix analysis of these products to get the overall rating based on different criteria like cost, operational cost, usability, and weight.

Twelve farmers from two villages, Sukewadi and Pimpalgaon Konzira of Sangamner Tehsil, Ahmednagar district, participated in this exercise to rate the products based on their experience of using backpack type of spraying equipment.

Table 6.5 shows the Pugh matrix for various backpack-type spraying products.

Table 6.5 Pugh matrix analysis of various backpack-type spraying products.

	Products				
					
Criteria	**Manually Operated**	**Battery Operated**	**Manual + Battery**	**Engine operated**	**Solar powered**
Cost	1	1	-1	0	0
Operational Cost	1	-1	0	-1	1
Usability	-1	1	1	1	1
Weight	1	0	0	-1	0
Positives	3	2	1	1	2
Negatives	-1	-1	-1	-2	0
Neutral	0	0	0	0	0
Total	**2**	**1**	**0**	**-1**	**2**

The Pugh analysis shows that manually operated and solar-powered spraying products are comparatively better than other available options. However, considering added advantages and functionality, the solar product could perform better than manually operated products. It defines the need for industrial design interventions to improve this product based on the user and field requirements.

Step 3. Component Level Deconstruction of the concept

The functional component is the pump. Its capacity is defined as per the spraying requirements. The associated electronic system is designed and developed with the help of technology experts (Protek Instruments from Pune took part in this exercise). Figure 6.7 shows the earlier defined waterfall model adopted for electronic system design.

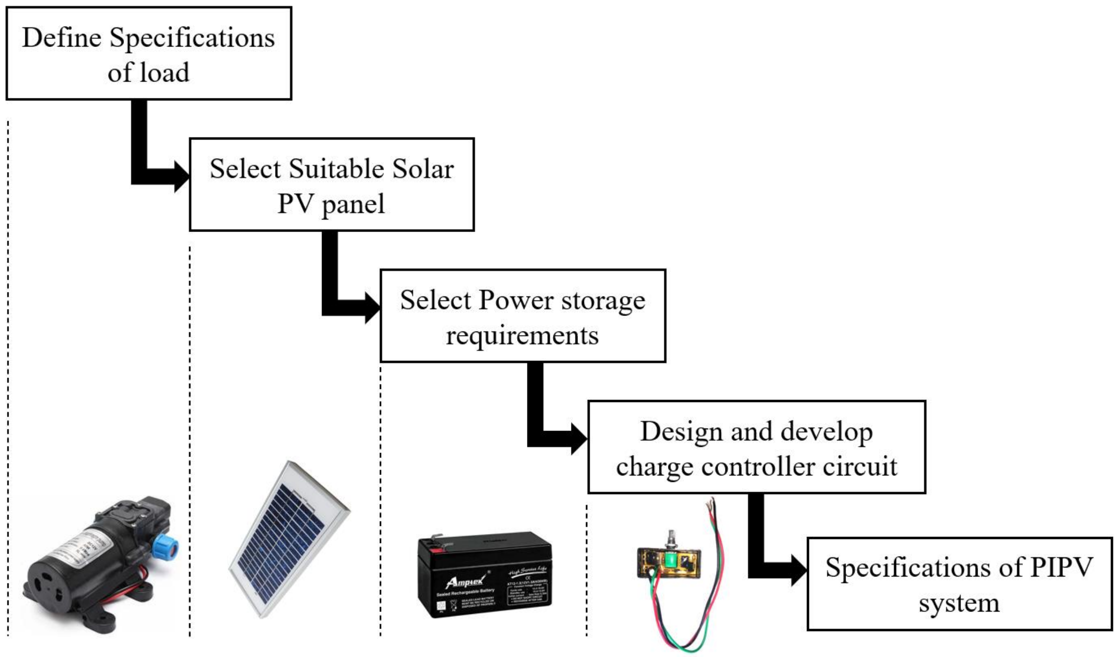


Figure 6.7 waterfall model adopted by technology experts to design and develop the electronic system required for spraying equipment.

Below are the specifications of various components shown in table 6.6

Table 6.6 Specifications of various components involved in the electronic system

System Design Step	Component	Specifications
Defining the Load specifications	DC pump	Voltage 12 V, Current Max 3 Ampere, Flow 4 – 5 Liter/minute. Dimensions 120 X 80 X 90 mm
Selection of PV panel	Solar PV Panel	12 Volt, 1.3 Ampere 20 Watt, Dimensions 200mm X 150 mm X 20mm Thickness

System Design Step	Component	Specifications
Power storage requirements	Li-ion battery	12 Volt 1.3 Ah, 99 mm X 44mm X 52mm
Charge Controller	Charge controller Circuit	10 Ampere, 12V DC, Dimensions 140mm X 78mmX80mm. Suitable up to 120 W solar PV Panel

Step 4. Sandbox iterations and development of the concept

The concept is generated using a PIPV sandbox model in which the parameter boundaries are defined considering user requirements. The concept is generated and iterated with the maximum possible attributes following the boundaries of the sandbox. Figure 6.8 shows the concept sketching iteration in the PIPV sandbox.

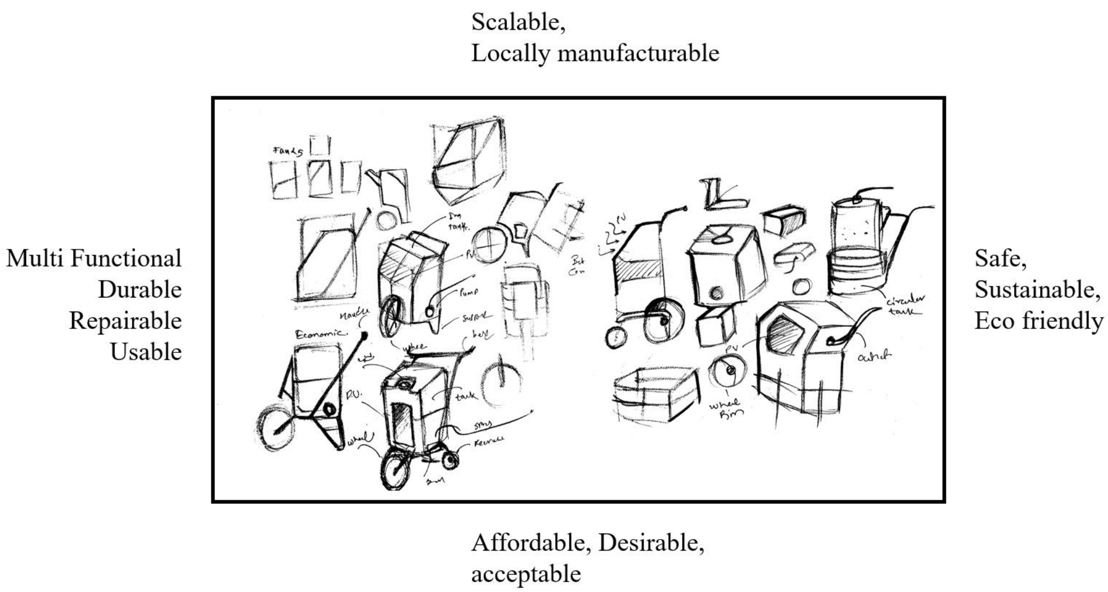
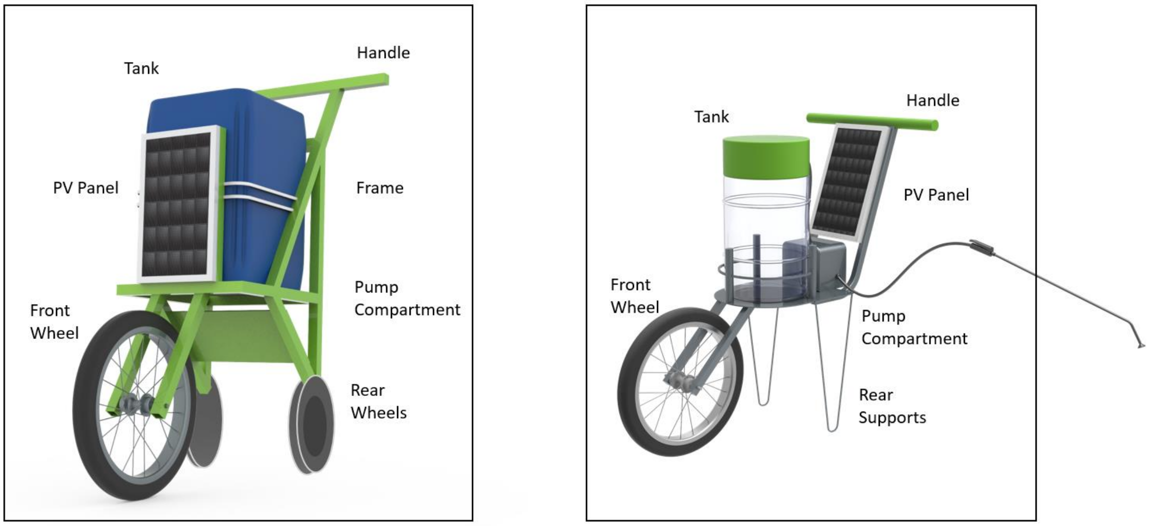


Figure 6.8 PIPV spraying device concept iterations in PIPV sandbox.

The concepts generated in iterative sketches using the PIPV sandbox are then explored using CAD software for their 3D visualization. Two concepts are modelled using a 3D CAD tool and rendered for better visualization. Figure 6.9 shows the 3D CAD and rendered visualization of two concepts. While iterating the concepts, the functional improvements are focused on considering parameters like affordability, desirability, scalability, and local manufacturability of the concept. Materials available in the local market are adopted to improve the sustainability factors in the concept. Several issues like the weight on the back of the user, frequent refilling of the tank, limited battery capacity and affordability are considered for the improvement in generated concepts. Affordability is the primary factor that decides users' acceptance of the solution, especially in the market catering to rural and remote places of India.



Concept 1

Concept 2

Figure 6.9 3D rendered visualization of concepts of PIPV sprayers generated using PIPV sandbox and input information on electronic system design parameters.

From concept one and concept two, the primary cost analysis is done, from which it is observed that the bent frame and cylindrical shape of the tank increase the cost of the product. Also, the special bending of the metal frame facility is difficult to get in local fabrication workshops. The tank and frame used in the concept can be produced at a lower cost. The rectangular shape of the tank makes it modular and replaceable with any similar tank which is commonly available in the market. The PV panel is attached to the front of the product, which has a mechanism to set the angle for charging it. Some of the improvements made are listed below

- The frame and trolley are designed with wheels to avoid lifting heavy weight on the user's back.

- A rectangular tank similar to the tanks available in the market for other purposes is used. It makes the tank capacity adjustable by replacing it with a different tank.
- Tank capacity is increased to 30 litres to avoid the number of refilling.
- PV panel and electronic systems are adopted to charge the battery on farm fields. It avoids the dependence of spraying activity on electricity.
- As there is no weight on the back, the user can handle the long length of the spraying hose to spray the liquid on all the sides of big crops like fruit trees.
- The trolley is designed so that it can be separated from all the mechanisms to use it for other tasks like carrying farm goods.
- The targeted cost of the product is kept in the band of INR 3500/- to 4000/- to ensure its acceptability by users.

Concept one is considered for further prototype development. The manufacturing drawings are generated using CAD tools. Figure 6.10 shows the manufacturing drawings and dimensional details of the concept.

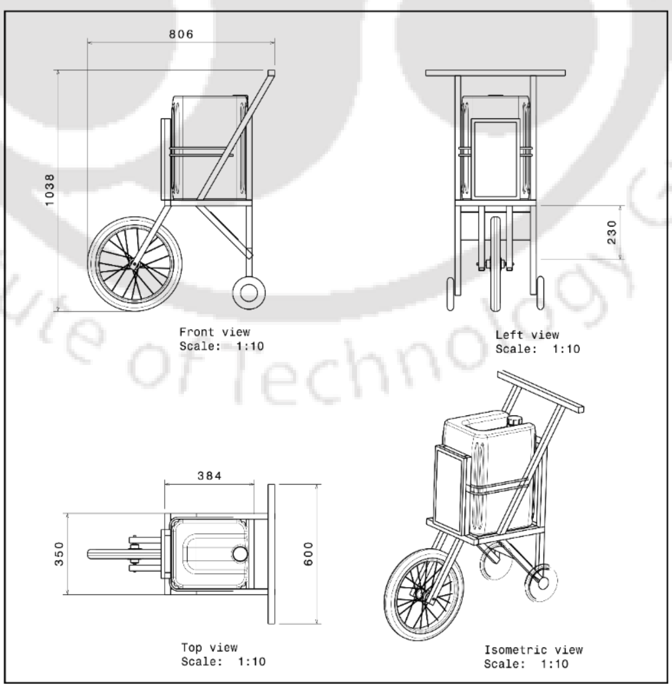


Figure 6.10 2D drawings for the prototyping of the concept.

The concept is then prototyped using a locally available manufacturing setup. The standard mild steel square tube 2.6 mm thick (12 gauge) is used to fabricate the frame. The functional components like the pump, battery and PV panel with defined specifications from the PIPV electronic system design are procured from the market. Below are the steps of prototype execution shown in figures 6.11 and 6.12.

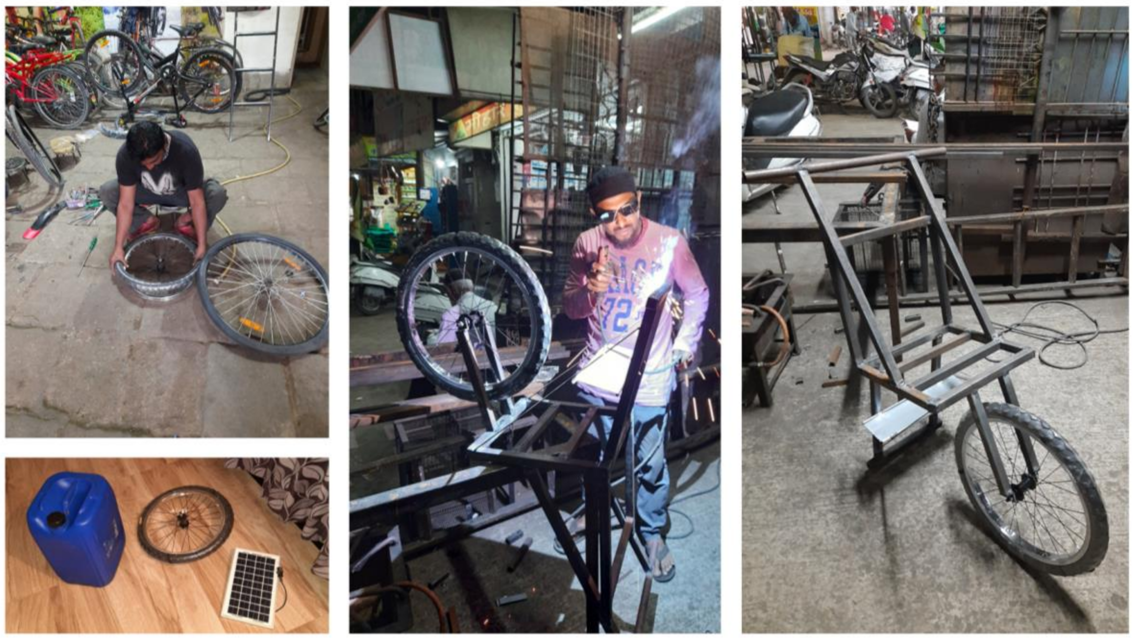


Figure 6.11 procurement of components and fabrication of frame of trolley.

Figure 6.12 Fitment of components on frame and finalization for powder coating

Figure 6.13 shows the final working prototype of the concept. This prototype is tested by its users, and based on their feedback, it is evaluated in the field.

Figure 6.13 Working prototype of PIPV agricultural sprayer concept.

A fully functional prototype is carried to farms for field testing with users to two villages, Sukewadi and Pimpalgaon Konzira of Sangamner tehsil, Ahmednagar district of Maharashtra state. The product is tested with farmers from various age groups, including male and female users, to observe its use. Observing users while doing the spraying activity and interviewing them about their thoughts about the product helped collect valuable feedback. The user feedback is collected based on the attributes defined in the spider-web analysis model to know the improvement parameters for the product.

Figure 6.14 shows the testing of the product with farmers, including those above 55 years of age, female farmers and users under the age of 20 years with big and small crops in farm fields. In big crops, the fruit trees of guava and mango were available for spraying, while the small crops of maize, onion and wheat were available for testing. Feedback is recorded on the hard copy forms prepared in the regional Marathi language for the convenience of users. These forms are included in appendix V.

Figure 6.14 A- Testing with big crop guava, B- Testing with Big crop Mango, C- Testing on small crop Maize, D- Testing with the female user on small crop wheat, E- testing with the female farmer on big crops, F- testing with users from age group under 18 years on small crop onion.

Step 5. Spiderweb analysis and comparison of the concept

The PIPV product prototype is evaluated based on the spiderweb analysis model. Users are asked to rate the product based on Affinity, Usability, Functionality, Desirability, Affordability, Acceptability, Durability and Repairability. Eight farmers participated in the survey to use and rate the product based on these attributes. Figure 6.15 shows the spider web model for the PIPV product prototype compared with the battery-operated backpack-type product.

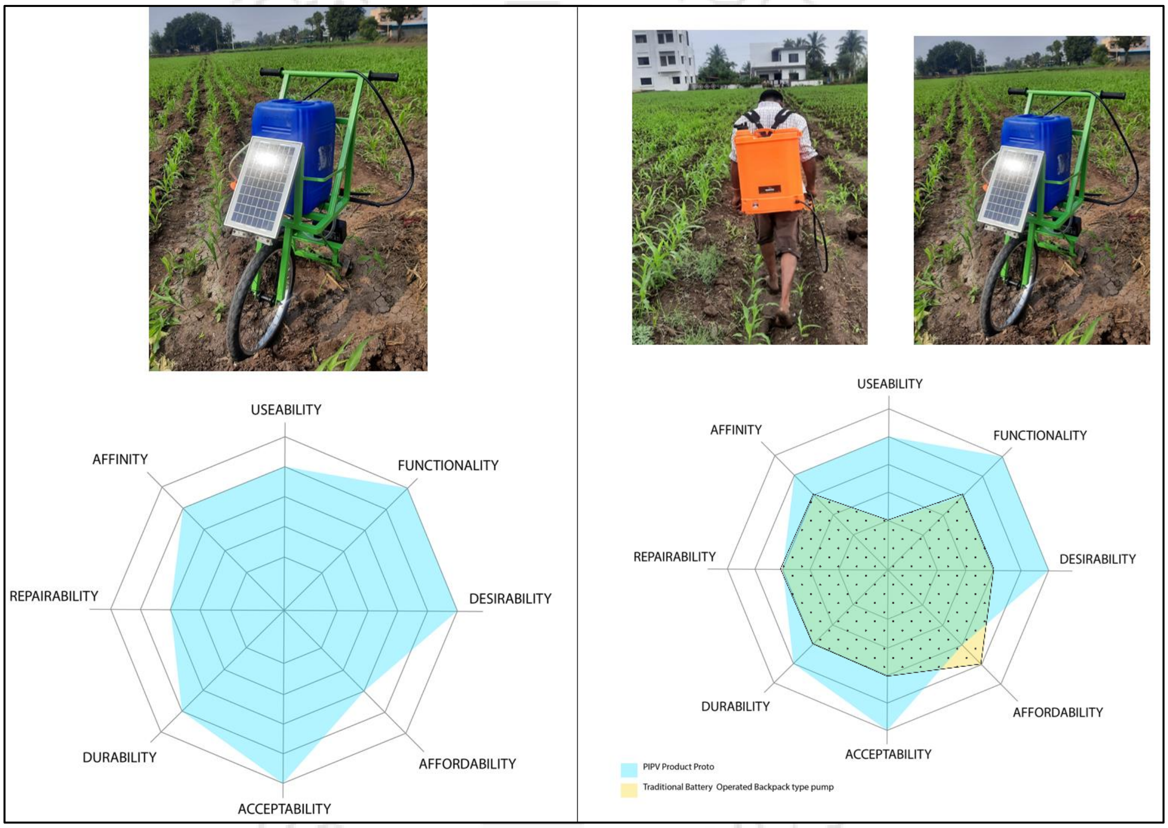


Figure 6.15 Spider web analysis of PIPV product prototype and its comparison with traditional backpack type battery-operated product.

Comparing the PIPV sprayer to the traditional backpack, the PIPV sprayer scored highly on the parameters of functionality, usability, desirability, acceptability, durability, and affinity. As the PIPV product concept's estimated cost was slightly higher than the traditional product, it scored low on affordability. Both the traditional and PIPV product poses the same rating on repair-ability due to the involvement of the electronic system.

Step 6. Refinement of the concept

From the testing and analysis of the PIPV product concept, it can be improved on its affordability. The cost optimization and mass production will improve the product concept. Spider-web analysis indicated the improvement areas for the PIPV concept based on user requirements.

Observations

Below are the observations recorded after testing the product prototype in the field.

- The product is tested in the field with various users for different types of crops; it performed as expected for the large crops while needing further modifications to suit a variety of other crops and field patterns
- It is observed that the product is highly aspirational due to its increased capacity and the addition of PV technology to it.
- The improved functionality and low cost of the product make it stand out from the traditional products. Despite the requirement for modifications, the product received positive feedback from the users especially compared to traditional products.

6.5 Chapter Summary

In this study, a step-by-step approach for designing PIPV products in a rural Indian environment is proposed based on the results from the research studies. The six-step approach contributes to each phase of the design of PIPV products. This approach is validated in designing and developing a PIPV agricultural spraying device. The product was conceptualized and developed following the steps of the proposed approach. It was found fulfilling the technical requirements for its functioning and successfully met user requirements and acceptance.

CHAPTER 7

Conclusions

This chapter summarizes the findings from various research studies and the contributions made from this study. It also describes the limitations of the study and outlines the scope of future directions that are possible with concluding closing remarks.

7.1 Introduction

The research was set out to explore the Industrial Design interventions focusing on PIPV to address the electricity-dependent needs of the rural areas in India. The intersection of these three pillars viz Industrial Design, PIPV and rural needs, defined the research's aim, objectives, and overall flow, focusing on developing context-appropriate PIPV products that meet the identified rural needs. Various studies were conducted to address the respective enquiries associated with the research. This concluding chapter summarizes the findings from various experimental studies undertaken during this research in addressing the research enquiries. It also describes the limitations of the research outcomes with comments about the scope of enquiry that may be pursued in the future. It summarizes the key contributions made through this study.

7.2 Review of Research aim and Objectives

The primary aim of the research was to identify the possible approach for the industrial design and development of PIPV products for rural communities of India. This was met through a state of art review of published literature. This review helped identify the research gap and define the scope of the research enquiry. This set the stage for outlining the key research questions, the aim of the research and planning the objectives. The research by abduction approach was adopted as the mode of research enquiry. The enquiries and the key research questions were:

Enquiry 1. What are the potential areas of intervention for PIPV products in rural India, and what are the needs of users that designers should consider? The findings gathered in this study addressed the two research questions associated with this enquiry.

Research Question 1: What are the crucial electricity-dependent needs of rural people that can be addressed through PIPV product interventions by designers?

The first objective of the research was to identify the possible intervention and focus areas for the design interventions in PIPV, considering the needs to be met in rural communities of India. These were identified by conducting the research studies by undertaking field visits to multiple village locations in Maharashtra and Meghalaya; user interactions with the farmers and other local community members of the village. Direct observations of their various living activities aided in identifying intervention possibilities that can contribute to enhancing local lifestyle needs. The outcome of this field study resulted in shortlisting various possibilities for product intervention that support user activities under four significant domains: agriculture, healthcare, education and household. This set the direction for outlining the design brief for a team of designers in conceptualization and idea generation experiments.

Research Question 2: What are the available PIPV interventions in the market, and what user needs do they address?

One hundred PIPV products are commercially available in the Indian market, and fifty grass-root innovations were first identified and reviewed. These interventions were mapped on a matrix following Maslow's hierarchy of human needs model to identify the aspirational user needs they address. It was found that the majority of commercialized PIPV products address the safety, self-actualization and self-esteem level needs. In contrast, grass-root innovations in PIPV focused on addressing rural communities' basic physiological needs. These were, however, not being addressed by the commercially available products. This gap directed the research towards interventions of PIPV product solutions that must address the bottom layer of basic human needs that rural communities seek.

Further, our review of interventions made by designers in PIPV product development showed that it is rather sparse and random across the different layers of aspirational needs. A more concerted product intervention that specifically addresses the basic physiological and security needs of rural activities is desirable. PIPV product intervention through good industrial design could be transformative in enhancing the lives of rural communities.

Enquiry 2. What are the challenges in developing PIPV products; the type of support and input information required for Industrial designers in each phase of the PIPV product development process?

This enquiry is addressed by seeking answers through the three sub-questions listed below

Research Question 3: What factors affect the industrial design process of PIPV products, and is there any support required for it?

The second objective of the research was to study and focus on the PIPV product design and development process. The aim was to identify the challenges and support required for the designers during the different phases of PIPV product development. This is achieved by conducting open-ended and scenario-based experiments with industrial designers. A common practice in most rural households observed was cooking on a firewood cook-stove. A design experiment was undertaken as a case for the generation of design concepts seeking novel ideas for various cooking activities appropriate for rural kitchen environments. A design brief was suitably developed for ideating conceptual solutions engaging a team of trained designers. The team was provided with supporting photo images of the real-life scenario of the kitchen environment in a typical village setting. Significant insights were gathered from this study about the challenges the participating designers faced in the conceptualization design process of PIPV products in a rural context. This design experiment opened the possibility of the Sandbox model as an effective means to guide designers in idea generation within realistic contextual parameters of rural activities. Considering the involvement of solar PV panels and electronic systems in the functioning of all the PIPV products, an understanding of technical information and inputs about solar PV panels and electronic systems emerged as crucial factors for the design and development of PIPV concepts. As solar PV and electronics system design requires specific expertise, designers need external support in their team from technology experts to configure the required electronic system to address and develop the functional aspects of a PIPV based product concept. Also, pragmatic inputs regarding the size and specifications of solar PV panels help designers in the configuration and visualization of product form that is more realistic. This critical input impacts decisions towards improvement on other critical design-related parameters, including ergonomics, handling and usability.

Research Question 4: How does the PIPV product transform from the ideation phase to the realization phase with the input information and support in each phase of development?

Considering the development of the PIPV air blower for firewood cook-stove as a case, it is seen that the PIPV concept can significantly be transformed from its ideation stage to the realization stage after it is developed with pragmatic inputs regarding solar PV panels and related electronic systems. After an objective assessment, the final product proposal can show significant improvements in the form factor, handling, usability and functionality. After field testing with end-users, feedback from the field indicates that even at the prototype stage, the proposed design continued to lag in meeting a few user requirements. There is an iterative need for taking periodic user feedback during the different stages of the product development cycle to ensure success and product acceptance while designing the PIPV product for use in rural India.

Research Question 5: What evaluation model can be adopted to evaluate the PIPV products in a rural context?

To evaluate the PIPV products based on user feedback, the spider-web analysis model (an established method for analysis) has been found effective. This model is validated with the users from rural communities. The spider-web analysis model helps graphically visualize the product concept's improvement factors. Also, it can be used to compare PIPV products and concepts with existing conventional products performing similar functions. The model is adopted throughout this research study.

In seeking the answers to the research questions associated with the above two inquiries, a systematic step-by-step approach for designing and developing PIPV products for rural context is proposed. This six-step approach in PIPV product development undergoes the concept design stage, system level–detail design stage, and testing-refinement stage of the development process.

Enquiry 3. What should be the possible approach to proceed with the Industrial design and development of PIPV products in a rural context?

The third objective of the research was to define and validate the proposed approach for Industrial design in the development of PIPV products for rural communities. The objective was achieved by combining the findings from the earlier two research enquiries; the methods adopted in the Product review of existing PIPV products and grass-root innovations combined with the findings from the design experiments in concept development undertaken with the designers. It set the direction for finalizing the early stage of the design process. Two products: the PIPV air blower for firewood cook-stove and PIPV agricultural insecticide/fertilizer spraying equipment, were taken up as a real-world case of design and development to see the process through up to the design refinement and prototyping stage. It helped finalize the PIPV product design and development process from scratch.

Developing a PIPV agricultural insecticide/fertilizer spraying device was undertaken as a case to validate the proposed design process for PIPV product development. It was subject to all six proposed stages of product development. The prototypes were taken to the village community and tested in the farms for feedback. Completing the process of validating that approach by designing, developing, and testing the PIPV products in the field. It is observed that after following the systematic approach, the concept met the functional and user requirements quite successfully. The process is seen to reduce the possibility of rejection of the concept by target users from rural India. Also, following this systematic approach to product development, designers can optimize the lead-time in transforming the PIPV concept into a market-ready functional prototype.

7.3 Limitations of study and scope for further research

Appropriate methods and models were adopted during this research towards seeking answers to the research questions, and their respective outcomes are summarized in the research progression diagram. This schematic process flow diagram highlights the stages and direction of the research.

However, there are a few limitations to this study that the researcher must mention.

- While the scope for Photo-voltaic applications is very vast, this research has focused on examining the product development process for only off-grid applications of PV systems limited to PIPV product development for rural context only.
- Due to the limited accessibility to rural places, the four villages from Maharashtra and two villages from the Meghalaya state of India were selected for the field study. These characterize rural environments for the plains and the hilly terrains, respectively. There may be different challenges to other topographic rural regions, such as the villages in coastal regions and desert regions. These may throw up new challenges for the product development process that were not experienced during this research study.
- Developed PIPV products are prototyped and tested with available resources. These concepts are open for further modifications during the commercially manufacturing stages.

Future scope for research:

The research suggests an approach for the Industrial Design of PIPV products through various studies and PIPV product development iterations. It opens up a new field for the Industrial design of PIPV products for India's rural communities. Also, the study suggests that there should be an interface between Industrial designers, Technology experts and product users; it can be explored and developed further by using various platforms. Developing a suitable digital interface to support designers with appropriate technical data is a distinct possibility. The link between Designers/ conceptualizers, Design Executors and Users as collaborating stakeholders can be established to achieve the success rate of PIPV products in the context of product development for rural India.

As noted in the earlier studies, there is a distinct need for professionally trained designers specializing in Photovoltaic technologies. Considering the present challenges in a global move towards sustainability, it is timely that new programs in Industrial Design for Sustainability be developed. Design processes in a new generation of PV product development may require that present programs in Design training be updated suitably. Academic experts may explore this at the earliest.

7.4 Research contribution and Conclusions

This research attempted to explore Industrial Design interventions focusing on the development of PIPV products, specifically addressing the context of meeting the needs of rural Indian communities. There are limited studies that address these three aspects together. The proposed systematic design processes the research has outlined will generate new knowledge that will help Industrial designers, Design Engineers, and Product executors willing to design and develop PIPV products that address the aspirational needs and expectations of rural communities in India. The research methods used for the experimental studies help gather directions for product conceptualization, development, refinement, and assessment. These have been validated to be effective. It is hoped that the systematic approach will contribute to and motivate aspiring designers in developing PIPV products and developing other range of PIPV products that meet challenges of rural domains of need, viz. agriculture, health, education and daily household needs.

During this research, various methods and experimental studies have been attempted that have contributed to the various phases of the design and development process of PIPV products. These pragmatic findings can be applied individually or in the form of an extracted approach for the development of PIPV products for rural communities of India.

Application of the steps defined in the extracted approach helps in improving the PIPV product concept based on technical and user requirements. It ensures the flow of required input information for designing PIPV product concepts and reduces the possibility of its rejection from potential users.

7.5 Closing remarks

The period of four years of fruitful time spent during this research has been gratifying and rich with continuous learning from the field. Engaging with local community members faced with challenges in the real world of rigorous agricultural labour and one of mutual interdependence strengthens community bonding. It has been enriching to learn from their field experiences and enrich the academic research that this researcher undertook.

To say the least, there is more this research has gained in comparison to what one has made through pragmatic outcomes that this research has been able to deliver. A word of thanks is due to all who have partnered in this journey.

List of Publications

1. Satpute, P. A., Shende, A., & Punekar, R. M. (2018, June). Role of Industrial Design in the Innovative applications of Solar Photovoltaic Energy for Rural India. In IOP Conference Series: Materials Science and Engineering (Vol. 377, No. 1, p. 012052). IOP Publishing.

2. *Pranav Satpute, Ravi Mokashi, Avinash Shende, Feasibility Tunnel: An Assistive Platform for Feasible and Innovative Idea Generation in Product Integrated PV (PIPV) Product Design, Grand Renewable Energy proceedings, 2018, Volume 1, Japan council for Renewable Energy, Pages 62-, Released March 07, 2019, Online ISSN 2434-0871, https://doi.org/10.24752/gre.1.0_62, https://www.jstage.jst.go.jp/article/gre/1/0/1_62/_article/-char/en

3. *Pranav Satpute, Pritam Paraye, Avinash Shende, Ravi .Mokashi, Product Integrated Photovoltaics: New Applications for Rural and Remote Areas of Developing Countries by an Industrial Design Approach, Grand Renewable Energy proceedings, 2018, Volume 1, Japan council for Renewable Energy, Pages 61-, Released March 07, 2019, Online ISSN 2434-0871, https://doi.org/10.24752/gre.1.0_61,https://www.jstage.jst.go.jp/article/gre/1/0/1_61/_article/-char/en

4. Satpute, P., Punekar, R. M., & Shende, A. (2019). Opportunity Areas for Industrial Designers to Explore New Applications of Product-Integrated Photovoltaics (PIPV) for Rural Communities of India. In Research into Design for a Connected World (pp. 413-422). Springer, Singapore.

5. Satpute, P., Punekar, R. M., & Shende, A. (2021). Approach for Industrial Design and Evaluation of Product-Integrated Solar Photovoltaic (PIPV) Products. In Design for Tomorrow—Volume 3 (pp. 511-521). Springer, Singapore.

References

Agoramoorthy, G., & Hsu, M. J. (2009). Lighting the Lives of the Impoverished in India's Rural and Tribal Drylands. *Human Ecology*, *37*(4), 513–517. https://doi.org/10.1007/s10745-009-9224-7

Apostolou, G., & Reinders, A. H. M. E. (2014). Overview of Design Issues in Product-Integrated Photovoltaics. *Energy Technology*, *2*(3), 229–242. https://doi.org/10.1002/ente.201300158

Blaschke, T., Biberacher, M., Gadocha, S., & Schardinger, I. (2012). " Energy landscapes ": Meeting energy demands and human aspirations. *Biomass and Bioenergy*, *55*, 3–16. https://doi.org/10.1016/j.biombioe.2012.11.022

Chakrabarti, S., & Chakrabarti, S. (2002). Rural electrification programme with solar energy in remote region – a case study in an island, *30*, 33–42.

Chandramouli, C. (2016). Rural urban distribution of population. Census of India. 2011.

CHANDRAMOULI, D. C. (2011). RURAL URBAN DISTRIBUTION Census of India 2011, (July).

Corporation, P. (2013). Panasonic Launches 100 THOUSAND SOLAR LANTERN PROJECT. Retrieved from https://news.panasonic.com/global/stories/2013/21707.html

d.Light. (2020). d.light Solar Products. Retrieved April 22, 2022, from https://www.dlight.com/products/

del Río, P., & Burguillo, M. (2009). An empirical analysis of the impact of renewable energy deployment on local sustainability. *Renewable and Sustainable Energy Reviews*, *13*(6), 1314–1325. https://doi.org/https://doi.org/10.1016/j.rser.2008.08.001

Ecosolatec. (2011). *Solar Trap*. Retrieved from https://www.youtube.com/watch?v=1hUivCPE-PE

Faiers, A., & Neame, C. (2006). Consumer attitudes towards domestic solar power systems. *Energy Policy*, *34*(14), 1797–1806. https://doi.org/10.1016/j.enpol.2005.01.001

Flipsen, S. F. J., Jansen, A. J., Bremer, A. P., & Veefkind, M. (2004). Towards a selection method for alternative energy systems in consumer products. *Tmce'04*, 1–8.

Fraas, L. M. (2014). History of solar cell development. In *Low-cost solar electric power* (pp. 1–12). Springer.

Gretebeck, L. J. (2017). The Socioeconomic Impact of Solar Lighting on the Rural Poor in India: A Case Study of Panasonic Corporation's Solar Lighting CSR Initiative. *共立国際研究= The Kyoritsu Journal of International Studies: 共立女子大学国際学部紀要*, (34), 11–22.

Harish, S. M., Iychettira, K. K., Raghavan, S. V, & Kandlikar, M. (2013). Adoption of solar home lighting systems in India: What might we learn from Karnataka? *Energy Policy*, *62*, 697–706. https://doi.org/https://doi.org/10.1016/j.enpol.2013.07.085

Herrando, M., & Markides, C. N. (2016). Hybrid PV and solar-thermal systems for domestic heat and power provision in the UK : Techno-economic considerations. *Applied Energy*, *161*, 512–532.

https://doi.org/10.1016/j.apenergy.2015.09.025

Hoed, R. Van Den. (2003). Design Guidelines for the Integration of Renewable Energy into Consumer Products. *Technische Univeriteit Eindhoven*. Retrieved from http://www.idemployee.id.tue.nl/g.w.m.rauterberg/conferences/cd_donotopen/adc/final_paper/645.pdf

Howell, B. F., Stark, C. G., Christiansen, T. J., Hofstrand, R. H., Pettit, J. L., Van Slooten, S. N., & Willett, K. J. (2016). Introducing New Design Disciplines into a Traditional Industrial Design Program. *DS 85-2: Proceedings of NordDesign 2016, Volume 2, Trondheim, Norway, 10th-12th August 2016*, 208–215.

Hsu, W., & Woon, I. M. Y. Y. (1998). Current research in the conceptual design of mechanical products. *Computer-Aided Design*, *30*(5), 377–389. https://doi.org/10.1016/S0010-4485(97)00101-2

ICSID. (2015). Difinition of Industrial Design. Retrieved March 11, 2021, from https://wdo.org/about/definition/

Iovino, F., & Tsitsianis, N. (2020). The Methodology of the Research . In *Changes in European Energy Markets* (pp. 79–95). Emerald Publishing Limited. https://doi.org/10.1108/978-1-83909-107-020201004

Jain, V. K., & Srinivas, S. N. (2012). *Empowering rural India the RE way: inspiring success stories.*

Jennings, P. (2009). New directions in renewable energy education. *Renewable Energy*, *34*(2), 435–439. https://doi.org/10.1016/j.renene.2008.05.005

Jolly, S., Raven, R., & Romijn, H. (2012). Upscaling of business model experiments in off-grid PV solar energy in India. *Sustainability Science*, *7*(2), 199–212. https://doi.org/10.1007/s11625-012-0163-7

Joshi, A. (2016). Innovating India: Solar-Powered Garbage Cans to Signal When Full. Retrieved April 21, 2017, from http://trak.in/tags/business/2016/03/21/innovating-india-solar-powered-garbage-cans/

Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K. (2018). Solar energy : Potential and future prospects, *82*(October 2017), 894–900. https://doi.org/10.1016/j.rser.2017.09.094

Lotter, B. (2013). *Manufacturing assembly handbook.* Butterworth-Heinemann.

Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, *50*(4), 370–396. https://doi.org/10.1037/h0054346

McLeod, S. (2007). Maslow’s hierarchy of needs. *Simply Psychology*, *1*, 1–8.

Members, R. E. N. (2020). *Renewables 2020 global status report 2020*.

Millinger, M., Mårlind, T., & Ahlgren, E. O. (2012). Evaluation of Indian rural solar electrification: A case study in Chhattisgarh. *Energy for Sustainable Development*, *16*(4), 486–492.

Mohanty P., Muneer T., Gago E.J., K. Y. (2016). Solar Radiation Fundamentals and PV System Components. *Solar Photovoltaic System Applications. Green Energy and Technology*. *Springer*. https://doi.org/https://doi.org/10.1007/978-3-319-14663-8_2

Panasonic Corporation. (2015). Initiatives in India bringing light to all those in need. Retrieved September 10, 2019, from https://panasonic.net/sustainability/en/lantern/2015/12/india.html

Pedraza, J. M. (2020). Solar Energy in Latin America and the Caribbean : The Current Situation and Perspectives in the Use of Solar Energy for Electricity Generation, 17–41.

R.S.Hiremath. (2021). Flexitron- RS HIREMATH INNOVATIONS UNLIMITED. Retrieved March 18, 2021, from https://www.flexitron.com/

Ravindranath, N. H., & Ramakrishna, J. (1997). Energy options for cooking in India. *Energy Policy*, *25*(1), 63–75.

Reinders, A. H., Diehl, J. C., & Brezet, H. (2013). *The Power of Design: Product Innovation in Sustainable Energy Technologies*. John Wiley & Sons.

Reinders, A. H. M. E. (2002). Options for photovoltaic solar energy systems in portable products. In *proceedings of TMCE, Wuhan, China.*

Reinders, A. H. M. E., & Sark, W. G. J. H. M. Van. (2012). *Product-Integrated Photovoltaics Technical Aspects of PIPV. Comprehensive Renewable Energy* (Vol. 1). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-087872-0.00140-2

Reinders, A. H. M. E., & Van Sark, W. (2012). 1.34-Product integrated photovoltaics.

Sahay, A. (2016). Peeling saunder's research onion. *Research Gate, Art*, 1–5.

Saini, N., Jain, S., & Krishen, K. (2015). Innovative Solar Power Technology Development for Rural Communities of India. *IETE Journal of Education*, *56*(1), 8–19. https://doi.org/10.1080/09747338.2015.1044037

Saini, R. P., & Sharma, M. P. (2010). Integrated renewable energy systems for off grid rural electrification of remote area. *Renewable Energy*, *35*(6), 1342–1349. https://doi.org/10.1016/j.renene.2009.10.005

Saunders, M., Lewis, P., & Thornhill, A. (2007). Research methods. *Business Students 4th Edition Pearson Education Limited, England*.

Sharma, N. K., Tiwari, P. K., & Sood, Y. R. (2012). Solar energy in India: Strategies, policies, perspectives and future potential. *Renewable and Sustainable Energy Reviews*, *16*(1), 933–941. https://doi.org/10.1016/j.rser.2011.09.014

Shukla, A. K., Sudhakar, K., Baredar, P., & Mamat, R. (2018). Solar PV and BIPV system: Barrier, challenges and policy recommendation in India. *Renewable and Sustainable Energy Reviews*, *82*, 3314–3322. https://doi.org/https://doi.org/10.1016/j.rser.2017.10.013

Singh, K. (2016). Energy for Sustainable Development Business innovation and diffusion of off-grid solar technologies in India. *ESD*, *30*, 1–13. https://doi.org/10.1016/j.esd.2015.10.011

Solanki, C. S. (2015). *Solar photovoltaics: fundamentals, technologies and applications* (Third). Phi learning pvt. Ltd.

Solanki, C. S., & Mudaliar, S. (2010). Strategies to target rural PV market in developing countries - A perspective. *Conference Record of the IEEE Photovoltaic Specialists Conference*, 2392–2396. https://doi.org/10.1109/PVSC.2010.5614367

Solarmango. (2014). Drivers of off grid Solar Market growth. Retrieved April 21, 2017, from http://www.solarmango.com/Biz/Off-Grid/Drivers+of+Off-grid+Solar+Market+Growthin+India

Solli, H., & Muller, G. (2016). Evaluation of illustrative ConOps and Decision Matrix as tools in concept selection. In *INCOSE International Symposium* (Vol. 26, pp. 2361–2375). Wiley Online Library.

Sun, D., & Wang, L. (2016). Research on heat transfer performance of passive solar collector-storage wall system with phase change materials. *Energy & Buildings*, *119*, 183–188. https://doi.org/10.1016/j.enbuild.2016.03.048

Suryoday, M. (2014). Anand Yaatri: Voyager of Happiness. Retrieved June 5, 2016, from https://amoalsale.wordpress.com/2014/01/29/suryoday-dec-2013-drive/

TED. (2013). *Richard Turere: My invention that made peace with lions*. Retrieved from https://www.youtube.com/watch?v=RAoo--SeUIk

Ulrich, K. T. (2003). *Product design and development*. Tata McGraw-Hill Education.

Urpelainen, J. (2014). Energy for Sustainable Development Grid and off-grid electri fi cation : An integrated model with applications to India ☆. *Energy for Sustainable Development*, *19*, 66–71. https://doi.org/10.1016/j.esd.2013.12.008

Veefkind, M. (2004). INDUSTRIAL DESIGN AND PV-POWER , CHALLENGES AND BARRIERS 3 . Development of the Solar Tergo, (Proceedings of the ISES EuroSun Congres).

Wamukonya, N., & Davis, M. (2001). Socio-economic impacts of rural electrification in Namibia: comparisons between grid, solar and unelectrified households. *Energy for Sustainable Development*, *5*(3), 5–13.

Whitehead, T. (2014). A framework for design and assessment of products in developing countries.

Whitehead, T. (2015). Enhancing new product development in low income economies. Loughborough University.

Youm, I., Sarr, J., Sall, M., & Kane, M. M. (2000). Renewable energy activities in Senegal: a review. *Renewable and Sustainable Energy Reviews*, *4*(1), 75–89. https://doi.org/https://doi.org/10.1016/S1364-0321(99)00009-X

Zerriffi, H. (2011). *Rural electrification: strategies for distributed generation*. New York: Springer. https://doi.org/10.1007/978-90-481-9593-0

Appendix I

Literature Review (highlighted studies closely related to the pillars of study)

Sr.	Publication	Authors	Topics discussed	Related pillar
1	Solar Energy in India: Strategies, Policies, Perspective and Future potential	N.K. Sharma et.al. 2011	*Solar is essential, although currently an underutilized energy source in India with the potential to offer an improved power supply (especially in remote areas) and increase the security of India's energy supply*	Solar PIPV
2	Understanding consumer attitude towards domestic solar power systems, using householders in central England.	Adam Faiers and Charles Neame 2006	*investigates householders' attitudes towards characteristics of solar systems and identifies some of the barriers to adoption, and informs future marketing activity. They recommended that suppliers and manufacturers should work closely with the early adopters to develop the operational, economic and aesthetic aspects of products.*	Solar PIPV
3	New directions in renewable energy education	Phillip Jennings 2009	*Most engineers are not trained to use these renewable energy technologies, and most are not aware of the principles of sustainability. There is, therefore, an urgent need to develop and implement new courses that prepare engineers, scientists and energy planners to work with renewables to produce sustainable energy generation systems. It applies to the field of design as well.*	Solar PIPV
4	Innovative solar power technology systems for rural India	Nitin Saini and Kumar Krishen 2015	*Their paper describes the development of innovative solar-powered based systems for use in rural communities of India. They mentioned that the cost and reliability of the supply of these energy sources had been a source of concern throughout rural India.*	Solar PIPV-Rural India
5	strategies to target rural PV market in developing countries-a a perspective	Chetan S. Solanki et.al. 2010	*This study is based on marketing and economic perspective and proposes various strategies to target rural PV Market like first targeting rural rich and then building on infrastructure to reach the base of the pyramid users*	Solar PIPV – Rural India

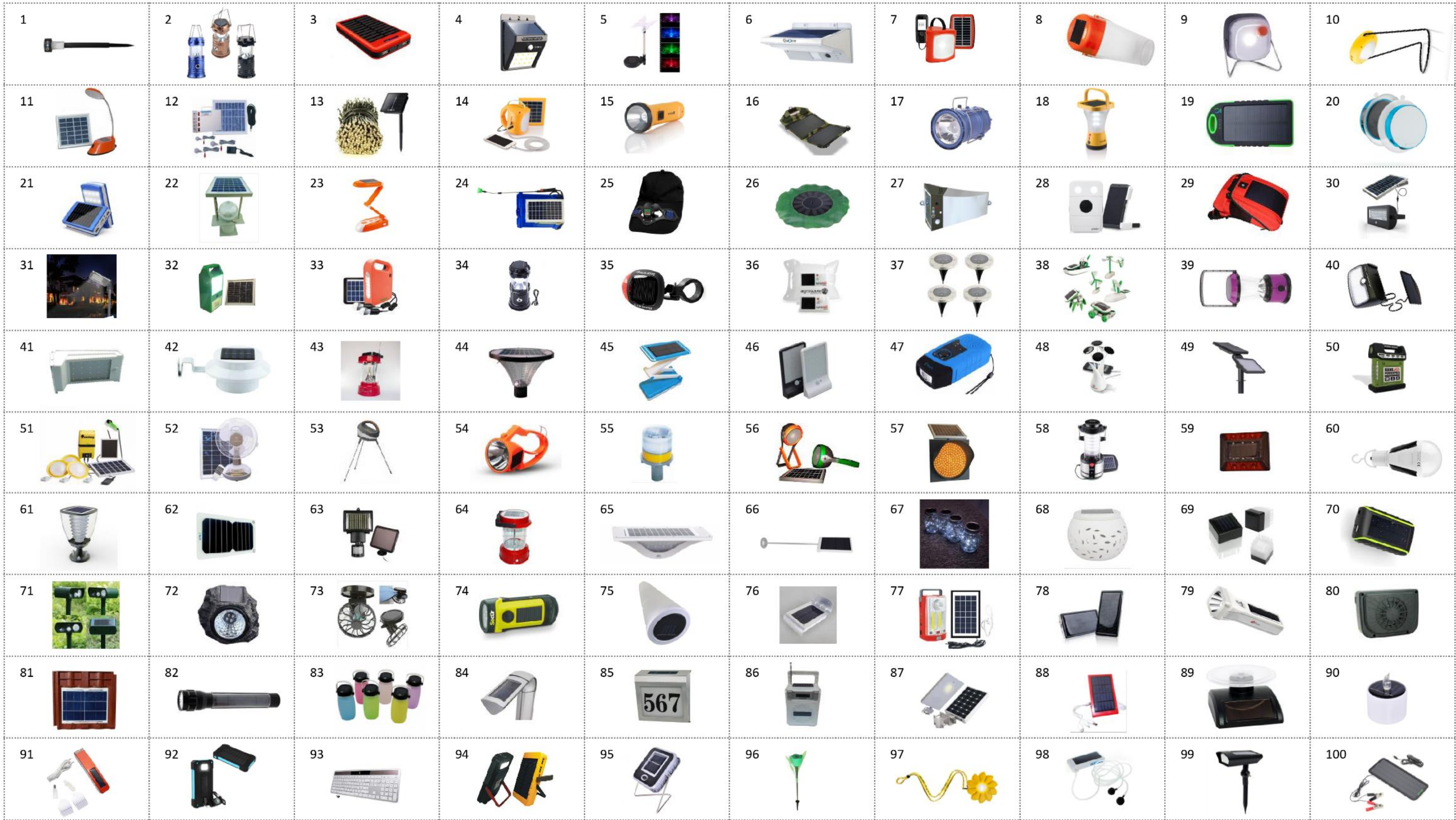
6	Empowering rural India the RE way: inspiring success stories	Ministry of new and renewable energy 2012	Includes the case studies about innovative interventions in solar photovoltaic technology in rural scenarios.	Solar PIPV-Rural India
7	The power of design: product innovation in sustainable energy technologies	A.H.M.E. Reinders	Describes various innovation methods from sustainable energy technologies with case studies about product designs from future and urban scenarios.	Solar PIPV – Industrial Design
8	Design Research through practice	Ilpo Kalevi Koskinen et.al. 2011	*advanced design practice as its starting point then enriches it to build a design process that can respond to academic and practical problems.*	Industrial Design
9	Selection Method for Designing Alternative Energy Systems in Consumer Products	Bas Flipsen et al. (2004)	*In order to support the design engineer in the early phases of the design process, a combined and comprehensive knowledge representation on the relative advantages and design consequences of alternative power sources should be available*	Solar PIPV – Industrial Design
10	'Industrial Design and PV-Power, Challenges and barriers	Menno Veefkind et al. (2004)	*Illustrates the part that industrial designers can play in developing new solar-powered consumer and personal products. Moreover, it goes into the specific problems that industrial designers experience when designing solar-powered products*	Solar PIPV – Industrial Design
11	Design guidelines for the integration of renewable energy into consumer products	Ana Mestre and Jan Carel Diehl (2003)	*Identifies the needs of guidelines while integrating renewable energies like Human power, Fuel cells and solar PV power in consumer products. According to them, applying these new energy technologies into product design is moving from an experimental phase towards a discipline in Industrial Design.*	Solar PIPV-Industrial Design
12	Options for photovoltaic solar energy systems in portable products	A.H.M.E.Reinders (2002)	*concludes that the field of application is relatively fresh, and many aspects have not been explored yet. Options exist because photovoltaic technology has proven to be feasible in high power applications and because of the expected Sharpe decrease of costs of photovoltaic materials*	Solar PIPV

13	Designing PV powered LED products-Integration of PV Technology in innovative products	A.H.M.E.Reinders and Andre de Boer	*Concludes regarding innovation that according to business models, innovation results in new markets for new products and services. Innovation is not just a matter of implementing advanced technology in existing products, but mainly a matter of sensing new opportunities which are created by new technologies such as LEDs and PV technology*	Solar PIPV – Industrial Design
14	Design Features of Product Integrated PV	Georgia Apostolou	*The thesis is a study about various aspects considering PIPV and Industrial Design engineering. It contributes as a database about technical, social and innovation aspects of PIPV product designs*	Solar PIPV
15	Integrated Product Design and Development	M.V.P. Pessoa & L.G. Trabasso	*Book chapter highlights the isses with product design and development process which results in incread lead time of product to come in market. It describes the importance and path of integrated product design process*	Industrial Design
16	A Comparison of Design features of 80 PV powered products	Apostolou G and A.H.M.E.Reinders	*Study analysed 80 various PIPV product on the basis of various technical parameters like battery capacity and application parameters.*	Solar PIPV
17	Bottom of pyramid as a source of breakthrough innovations	C. K. Prahlad 2011	*It identifies the bottom of pyramid as a new source of radicle innovations by focusing managerial attention on creating awareness, access, affordability and availability (4As)*	Rural India
18	Product Integrated PV applications – How industrial design methods yield innovative PV powered products.	A.H.M.E. Reinders 2008	*Study is all about the PIPV concepts produced from various Industrial design methods.*	Solar PIPV-Industrial Design
19	Design Inspired innovation for Rural India.	Sten Ekman et al 2011	*The purpose of this paper is to discuss an initiative between Swedish and Indian researchers, MBA students and their networks. It is based on appropriate design research methodology, ethnographic design research and innovation science. Experiences from initial empirical studies show that master students gathering data in the field (focusing in the areas*	Rural India

			such as ICT, banking & finance, health care, entrepreneurship, energy and agribusiness), analysing and interpreting the data together with researchers can get new insights of opportunities in innovation and entrepreneurship at the ´bottom of the pyramid´.	
20	Evaluating the future of Indian Solar Industry	Ganesh N. Prabhu, Professor	*India is a country that has tremendous solar energy potential. As the nation is facing an increasing demand - supply gap in energy, it is important to tap the solar potential to meet the energy needs. This article analyzes the Indian Solar industry, its major growth drivers, the challenges it faces and the various policy initiatives taken by the government. The article also tries to identify the various actions required to promote the growth and development of the industry, enabling India to meet the rising energy demands of the future.*	Solar PIPV
21	Design Studies for a Financial Management System for Micro-credit Groups in Rural India	Tapan Parikh et.al.	*Describes the design process, results and observations obtained in designing a user interface for managing community-based financial institutions in rural India. The primary users are semi-literate village women from local communities. We present detailed observations from our field visits and the resulting evolution in our design vision.*	Rural India
22	Photovoltaic technology for socially viable Product Design for Rural India	Alok Agashe	*Focus of book is on the Industrial Design, Solar PV and Rural scenario*	Industrial Design- Rural India- Solar PIPV
23	Everybody loves a good drought: stories from India's poorest districts	P. Sainath	*Book is about the observations about conditions and scenarios of poorest districts of India*	Rural India
24	Buying behaviour of rural and urban consumers in India: the impact of packaging	Mahavir Sehrawet and Subhash C. Kundu	*This study aims to establish whether the residential background of consumers has a varying influence on their buying decisions. Rural residents found that packaging is more helpful in buying, that better packaging contains a*	Rural India

			better product and that they are more influenced by the ease of storing a package than their urban counterparts.	
25	Development of technologies for rural areas – need for now thinking	Anil K. Rajvanshi	*A large number of voluntary organizations are involved in developing technologies for rural areas. However, these technologies have hardly touched the lives of rural population. Data on rural market potential shows that a population of about 250 million in rural areas exhibits a high level of market potential. This is almost 25% total population of India. With such a high market potential, why have the good efforts of organizations developing technologies, devices and products for rural areas not borne any fruit? This article tries to analyze the reasons and to give some possible solutions.*	Rural India – Industrial Design

Appendix II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567

Identified 100 PIPV Products are explained in detailed below

Sr.	Product Name	Description	Category	Price (₹)
1	Pathway Solar Lights for Gardens	Solar PV lights with sharp end to fix in garden. These are rechargeable automatic operation lights	Outdoor Lighting	1190
2	LED solar travel camping Lantern	Small camping light with solar panel. Product appearance resembles with conventional kerosene lantern	Indoor Lighting	238
3	Solar Power Bank	10000 mAh power bank with provision of USB ports for charging multiple devices	Charger	2699
4	Solar Light	Inclined wall mount light with motion sensor and LDR for automatic operation	Outdoor Lighting	750
5	Garden decoration Light	Solar powered butterfly light for gardens with stick to fix in soil.	Outdoor Lighting	950
6	21 LED Solar Light	Solar Powered LED light with motion sensor and automatic working with 21 LEDs	Outdoor Lighting	1990
7	Solar Light with Mobile charger	Solar light for emergency and ordinary use with provision of mobile charging port	Indoor lighting + charging	1895
8	Ultra-Flexible Solar Lantern	Solar lantern for outdoor and indoor use with provision of multiple use options.	Indoor + outdoor lighting	645
9	Solar Lantern	Solar light for stand to keep on desk or table with illumination levels button	Indoor lighting	325
10	Emergency Solar LED Light	Light with integrated solar panel and detachable stand. It can be used on desk or can be detached to use in emergency.	Indoor Lighting	2886
11	LED Table Lamp	LED table lamp with Solar panel provision with it. Lamp is specially design for on table use.	Indoor Lighting	850
12	Solar Home lighting system	Integrated system with solar panel, battery and Light bulbs.	Indoor Lighting	2950
13	Festival string light	Solar powered solar string light for decoration purpose.	Decoration	699
14	Solar Lantern	Solar powered lantern with mobile provision of mobile charging with it.	Indoor lighting + charging	1250
15	Solar Torch	Solar torch with integrated PV panel.	Outdoor lighting	449
16	Portable charger	Portable charger for changing multiple devices specially designed for outdoor use.	Charger	1099
17	Solar desktop light	Small solar powered light for desktop use	Indoor lighting	499
18	Indoor outdoor solar lantern	Solar lantern for indoor and outdoor use with maximum illumination	Indoor + outdoor lighting	1775
19	Solar power bank	Power bank with integrated solar panel for charging multiple devices.	Charger	945

20	Window Solar charger	Port is window solar charger with integrated solar power it is designed to use indoor.	Charger	
21	Power bank + light	Solar powered power bank with LED lights for used in emergency.	Charger +Lighting	1349
22	Gate Light	Entry Gate light with top mounted solar panel and high illumination light bulb	Outdoor lighting	2999
23	Foldable reading lamp	It is foldable and rechargeable solar powered reading lamp.	Indoor Lighting	249
24	Agricultural sprayer	Backpack sprayer with integrated solar panel and battery for its working	New Application	3799
25	Solar Cap with Fan	Cap with integrated solar panels and fam for cooling in bright sunny hot climate	New Application	500
26	Solar fountain	Solar powered fountain with integrated solar Panel for garden ponds	New Application	1200
27	Garden Light	Motion activated garden solar light	Outdoor lighting	3990
28	Solar Charger	Solar powered charger with an option of charging from grid power	Charger	10276
29	Solar Backpack	Backpack with integrated solar power for on the go charging of multiple devices.	New application	3499
30	Solar courtyard light	Courtyard or garden light with provided solar panel	Outdoor lighting	2750
31	Solar Street Light	Solar powered street light for use in streets and gardens	Outdoor lighting	20000
32	Solar task lamp	Task lamp with provided solar panel, it can be used indoor and outdoor tasks	Indoor+ outdoor lighting	1700
33	Home lighting system	Home lighting system with inbuilt emergency light	Indoor Lighting	2200
34	Desk lamp with mobile charging	Desk lamp with integrated solar panel and mobile charging provision	Indoor lighting+ charging	295
35	Bicycle light	Light for cycling it is safety indicator light with integrated solar panel.	New application	349
36	Inflatable solar light	Solar panel integrated inflated light especially useful in emergency situations.	New application	1469
37	Ambient garden light	Waterproof Ambient garden lights with sharp end to fix in soil. PV panels are integrated with lights.	Outdoor Lighting	1750
38	Solar toy Kit	Solar panel toy modules for educational and learning purpose	New application	369
39	Solar Emergency light	Solar powered indoor light with integrated solar panel on top.	Indoor lighting	700
40	Wall light	Light with detachable solar panel and provision for mounting on wall.	Outdoor lighting	1999
41	Night light	16 LED night solar light with provision for mounting on wall and integrated solar panel.	Outdoor lighting	2699
42	Fence light	Solar power light with provision of attachment with garden fence.	Outdoor lighting	550
43	Solar light set	Solar light with inbuilt FM radio.	Indoor light	1995

44	Solar light for compound walls and gardens	Solar panel integrated light for compound walls/fence and gardens.	Outdoor lighting	2500
45	Foldable solar light	Solar powered light for desk use and reading purpose.	Indoor lighting	1500
46	Flat motion sensor light	Wall mount light with motion sensor and automatic operation.	Outdoor lighting.	1800
47	Solar powered FM radio	FM radio with solar panel and multiple functions like torch and mobile charging.	New application	2190
48	Solar charger	Solar charger in the form of indoor plant/tree	Charger	5499
49	Garden Light	Solar powered garden light set.	Outdoor lighting	2250
50	Solar home electric system	Heavy duty solar power home electric system with integrated solar panel. It can be connected to external panels.	Charger	9990
51	Solar Home lighting system	Solar Home lighting system with provided solar panel and LED bulbs	Indoor Lighting	5000
52	Solar Powered Fan	Solar Fan with DC motor and rechargeable battery it provided with separated solar panel	New application	3727
53	Stylish solar lamp	Solar Powered indoor lamp designed with emphasis on styling.	Indoor lighting	3019
54	Compact solar lantern	Solar PV panel integrated light for use as torch and an emergency light.	Indoor+ Outdoor lighting	320
55	Solar Delineator	Blink light with integrated solar panel specially designed for delineator	New application	1056
56	Solar lantern	Solar light designed with multi position placement stand	Indoor+ Outdoor lighting	1535
57	Solar Blinker	Solar powered blinker for road signaling	New application	13452
58	Solar lantern	Solar lantern with provided solar panel designed for illumination on all sides.	Indoor lighting	1465
59	Solar road stud	Blink light designed for road signaling purpose. Rigid and heavy-duty casing design	New application	858
60	Solar Bulb	Solar bulb integrated with solar panel	Indoor+ Outdoor lighting	600
61	Solar Gate light	Specially designed gate light with integrated solar panel and reflector for maximum illumination	Outdoor lighting	4450
62	Portable charger	Semi flexible solar charger for multiple devices	Charger	1875
63	Flood Light	Solar powered high illumination solar flood light	Outdoor lighting	2990
64	Emergency lantern	Lantern with integrated solar panel and USB charging provision.	Indoor lighting+ Charging	899
65	Wall Mount light	Solar powered high brightness wall mount light.	Outdoor Lighting	2250
66	Flexible street Light	Flexible and adjustable street light with integrated solar panel.	Outdoor lighting	1990
67	Jar lights	Solar powered decoration lights in jar for decoration of gardens and sit out places	Decoration	2728

68	Ceramic lamp	Color changing decorative ceramic lamp for outdoor decoration	Decoration	690
69	Fence post lights	Fence post pool side garden lights with integrated sola PV panel.	Decoration	470
70	Power bank	Power bank with integrated solar panel and hand crank for charging multiple devices.	Charger	3899
71	Animal Deterrent Repeller	Solar powered infrared wave animal repellent.	New application	1789
72	Rock lamp	Solar Rock stone lamp for garden and artificial fountain decoration	Decoration	569
73	Clip on fan	Clip with fan and integrated solar panel to clip on required locations.	New application	1299
74	Flashlight	Solar and hand crank powered flash light for use in emergency	Outdoor lighting	2000
75	Hanging lamp	Pathway hanging lamp with integrated solar panel and flexible conical light diffuser.	Decoration	535
76	Motion sensor light	Wall mount motion sensor light with metal bracket casing.	Outdoor lighting	990
77	Home lighting system	Solar home lighting system with emergency light.	Indoor lighting	1250
78	Power bank	Power bank with integrated solar panel to charge multiple devices.	Charger	1600
79	LED torch	LED torch with integrated solar panel.	Outdoor lighting	440
80	Auto Fan	Mini fan with integrated solar panel for use in cars and small compartments.	New Application	799
81	Solar Tile	Solar panel integrated in earthen tile like casing	New application	799
82	LED torch light set	LED torch with integrated solar panel	Outdoor + Indoor lighting	790
83	Jar lights matt	Diffused jar lights with integrated solar panel. Specially designed for outdoor and indoor decoration	Decoration	1199
84	Solar floor light	Floor light with integrated solar panel and mounting stand	Outdoor lighting	1200
85	Backlit number plate	Backlit display number plated with integrated solar panel	New application	990
86	Radio	AM/FM radio with integrated solar panel	New application	599
87	Adjustable street light	Adjustable soar street light with integrated solar panel	Outdoor lighting	1699
88	Charger	Solar panel with multiple charging pins for charging and experiments.	Charger	299
89	Display stand	Rotating display stand with integrated solar panel	New application	532
90	Candle light	Decorative light in the form of candle flame provided with integrated solar panel.	Decoration	498
91	Trimmer	Beard and hair trimmer with integrated solar panel and various attachments	New application	299
92	Power bank	Power bank with integrated solar panel and LED light	Charger	2299

93	Wireless Keyboard	Solar powered Wireless keyboard	New applications	9763
94	Power bank reading light	Power bank with integrated solar panel and reading light with reading stand provision	Indoor light + charger	1100
95	Desk light	Portable desk light with integrated solar panel	Indoor lighting	399
96	Flower light	Light in the form of flower and provided with integrated solar panel	Decoration	999
97	LED lamp	LED lamp in the form of flower and sun	Indoor lighting	899
98	Oxygenator	Solar powered oxygenator for pools and ponds	New application	5877
99	Lawn light	Lawn light for garden	Outdoor lighting	3916
100	Car battery charger	High efficiency semi flexible solar panel for charging and car battery charging	charger	2903

Appendix III

Grassroot innovations, Innovation attempts

Sr.	Innovation	Description	Accessed from
1	Solar Powered Water condensation	Solar energy used to desalinate water	http://gyti.techpedia.in/project-detail/to-alternate-get-resource-of-safe-water/32
2	Docile Solar Water Filter	Solar Powered water purifier	http://gyti.techpedia.in/project-detail/docile-solar-water-filter/40
3	Solar Energy Used In Air Condition	Solar Powered Air conditioning	http://gyti.techpedia.in/project-detail/solar-energy-used-in-air-condition/145
4	Automatic Solar Panel Equipment Cleaning Technology	Solar power cleaning for high efficiency	http://gyti.techpedia.in/project-detail/automatic-solar-panel-equipment-cleaning-technology/200
5	Automatically Maintained Lights With Antitheft Solar Tracking	Solar Street light with tracking technology	http://gyti.techpedia.in/project-detail/automatically-maintained-lights-with-antitheft-solar-tracking/298
6	Automated Solar Irrigation	providing ultimate farming solutions specially designed for rural areas. with effective utilization of solar energy to run the motor and microcontroller based automatic pumping circuitry the creation of this model is bound to provide decisive solution to rural irrigation woes.	http://gyti.techpedia.in/project-detail/automated-solar-irrigation/431
7	Solar Operated Energy Efficient Evaporative Air Cooler	evaporative cooling is an ideal and most economical method of cooling. cooling by water evaporation is a natural phenomenon which has been need for centuries and has become popular because of its properties such as simple, cheaper, efficient and eco-friendly. the evaporative cooler is the need of small roadside shops, departmental stores, pan shops, net cabins, fulfilling cooling requirements of a person sitting on the counter who can't afford to install window air conditioner due to its limitations. the limitations are overcome by evaporative air cooler, such as less space requirements, low power consumption, handy, portable, low initial cost, and does not require closed space.	http://gyti.techpedia.in/project-detail/solar-operated-energy-efficient-evaporative-air-cooler/579
8	Evacuated Tube Gh Solar Cooker	Evacuated tube solar cooker concentrates light to a larger surface, so it is more tolerant for marginal errors of alignment and supplies even amount of heat from all directions with minimum heat loss giving high cooking temperature up to 200 degrees	http://gyti.techpedia.in/project-detail/evacuated-tube-gh-solar-cooker/769
9	design Of Low Cost Solar Water Heater with Relatively Higher Efficiency	the project includes a review of existing design of a solar water heater and modifying the same based on principles of parabola to facilitate cost effectiveness and higher efficiency to cater to the use of larger consumer base	http://gyti.techpedia.in/project-detail/design-of-low-cost-solar-water-heater-with-relatively-higher/907

		at an affordable price. after deep study of various types of solar water heaters and parabolic trough collectors, we came to a conclusion that in order to achieve higher temperature, maximum concentration of sun rays is much necessary. So we decided to use the parabolic trough as by the use of parabola principle the sun rays once passing through the evacuated tube collector will be re-concentrated and hence higher temperature will be achieved.	
10	Very Low-Cost Day-night Solar Lighting Device for Rural India.	this device is a simple contraption which directly allows sunlight into the room through a reflective coated tube in the day time. during night, a solar powered battery would light up the room with ultra-bright LEDs. our tests proved that about 40% of power can be saved in each individual house with such an installation for lighting purposes.	http://gyti.techpedia.in/project-detail/very-low-cost-day-night-solar-lighting-device-for-rural/1026
11	Experimental Setup Of Solar Bicycle	a solar bicycle or tricycle has the advantage of very low weight and can use the riders' foot power to supplement the power generated by the solar panel roof. in this way, a comparatively simple and inexpensive vehicle can be driven without the use of any fossil fuels.	http://gyti.techpedia.in/project-detail/to-perform-the-experimental-setup-of-solar-bicycle/1109
12	Solar Distillation - Hot Water Dual Thermal System	this project report deals with a hybrid solar distillation system has been developed. it can be used to provide distill water as well as hot water. in the present experiment setup, the water gets converted into steam & steam is than condensed by external water ow. so, at the end the distillate & hot water, both are achieved parallel. the appropriate components such as receiver & condenser are designed and fabricated as a part of project work. experimentally it is found that the overall system efficiency as 41.02 % when the receiver is unshielded. further the receiver is shielded & the efficiency is improved as 56.12 %.	http://gyti.techpedia.in/project-detail/solar-distillation-hot-water-dual-thermal-system/1342
13	Solar Water Heater Using Concentric Collector	a step toward finding the most efficient way to collect and use the sun's energy can be taken by making small models of solar collectors and finding ways to improve their performance. solar energy is becoming an alternative for the limited fossil fuel resources. one of the simplest and most direct applications of this energy is the conversion of solar radiation into heat, which can be used in water heating systems. a commonly used solar collector is the flat-plate. a lot of research has been conducted in order to analyze the flat-plate operation and	http://gyti.techpedia.in/project-detail/solar-water-heater-using-concentric-collector/1633

		improve its efficiency or need to go for converting its design to concentric reflector collector.	
14	Solar Operated Closed-Circuit Television Camera	camera's work on electricity and consumes 10% electricity of each and every above organizations. hence it is our prime duty to conserve energy which is here in form of electricity. as we know solar energy is effective and efficient source thus we are generating electricity from photovoltaic cell or solar panel and utilizing it for security system in form of c.c.t.v. cameras.	http://gyti.techpedia.in/project-detail/solar-operated-closed-circuit-television-camera/1806
15	Solar Biomass Hybrid Drying System for Medicinal Plants	in solar biomass hybrid dryer, the best ranked thin layer drying model applicable to the variation of moisture ratio with drying time of turmeric samples were page model, two term models and modified henderson and pabis model, logarithmic model for turmeric dried in sbhd. the overall efficiency of biomass combustor for hot air generation was found to be 79.79 per cent. it is revealed that biomass combustor was able to produce sufficient hot air for drying of turmeric slices.	http://gyti.techpedia.in/project-detail/solar-biomass-hybrid-drying-system-for-medicinal-plants-its-design/2245
16	Solar Powered Railway Trolley	this project is based on the idea to convert conventional railway trolley used for the inspection of the railway tracks to run on solar power, hence would provide some relief to railway in terms of money and also in terms of conservation of environment	http://gyti.techpedia.in/project-detail/solar-railway-cart/2553
17	Solar Water Heater Made By Plastic Material	this project presents the advanced technology and some of the unique features of a novel solar system that utilizes solar energy for space heating and water heating purpose in residential housing and commercial buildings. the main goal of the project is depend on cost effective sources of energy with the help of material changing of panel	http://gyti.techpedia.in/project-detail/solar-water-heater-made-by-plastic-material/2580
18	Solar Powered Led Based Reading Device	In this project we will develop a solar powered led based reading device. in this we will use a 5-6 v dc storage rechargeable battery. during the day time solar panel in device will charge the battery using sunlight. charging circuit will consisting of ics (lm317), transistors, resistors, zener diode etc .	http://gyti.techpedia.in/project-detail/solar-powered-led-based-reading-device/2844
19	Defluorination Of Drinking Water and Rainwater Harvesting Using A Solar Still	an inclined basin-type solar still containing sand and water has been used at Bangalore for defluoridation. for water samples having a fluoride concentration in the range 5–20 mg/l, the fluoride concentration in the distillate was usually <1.5 mg/l. during the periods october 2006–may 2007 and october 2007–may 2008, the volume of distillate showed a significant diurnal	http://gyti.techpedia.in/project-detail/defluoridation-of-drinking-water-and-rainwater-harvesting-using-a-solar/3200

		variation, ranging from 0.3 to 4.0 l/m2•day.	
20	Serve (Solar Electric Road Vehicle)	his project was initiated with a goal of developing a cheap, efficient and environment friendly transportation solution. it led to the design & manufacturing of serve: solar electric road vehicle. “serve: solar electric road vehicle” is four wheeled two passenger seater solar electric vehicle. the length of the car is 4.4m width of 1.75m and height of 1.28m and weighs only 400 kgs. it uses 6m^2 monocrystalline silicon solar panels which can generate a power of more than 1kw at an efficiency of 20% which charges a battery pack consisting of lithium ion cells at a capacity of 13kwhr weighing 63 kg which gives the car a range of 250+ kms.	http://gyti.techpedia.in/project-detail/serve-solar-electric-road-vehicle/3462
21	Low Cost Multi Stage Water Purification System for Large Communities	the solutions that do not consume an excess of power generally require expensive and time-consuming filter maintenance. with the idea of low cost and sustainability in mind, we plan to develop a water filtration system that will take advantage of cost friendly and user-friendly processes along with natural energy in order to run a highly efficient water purification system. by using all our techniques, our goal is to get the outlet water quality, which is well under the limits of Indian standard specifications for drinking water (is: 10500).	http://gyti.techpedia.in/project-detail/low-cost-multi-stage-water-purification-system-for-large-communities/3506
22	Solar Charger For Rechargeable Batteries Used In Hearing Aid Devices	the solar charger is designed to avoid overflow of charging current through the battery through a current regulator. the rechargeable battery is charged at a constant current value of 6-7 ma. the charger is then tested for solar charging of battery until it gets fully charged. the solar charger charges the battery in almost 4-5 hours in almost all weather conditions. the fully charged battery can be used in hearing aid device for a complete day.	http://gyti.techpedia.in/project-detail/solar-charger-for-rechargeable-batteries-used-in-hearing-aid-devices/3656
23	Solar Based Air Cooler	design and construction of a solar based air cooler is a new alternative to air cooling that uses far less electricity and also uses energy from the sun to run the system. we set out to create an air cooler that does not create any harmful emissions and cuts down on the electricity cost to a home owner. the solar based air cooler uses solar power as the main energy source to help in the thermodynamic heat transfer process as well as heat transfer principles to convert ambient air into cool air.	http://gyti.techpedia.in/project-detail/solar-based-air-cooler/3936

24	A Hybrid Kitchen Stove That Works Indoors Using LPG And Solar Thermal Energy	using air as medium, high temperatures ranging from 350 degree c to 500 degree c have been achieved by employing parabolic solar concentrator. adapting the available models, a hybrid stove has been fabricated to fit into a typical middle class family kitchen. the outdoor concentrator unit supplies hot air and the indoor unit is a stove that works half on lpg and the other half on hot air. no need of standing in the hot sun as is the case with majority of earlier models. cooking is done both on hot air burners and lpg burners.	http://gyti.techpedia.in/project-detail/a-hybrid-kitchen-stove-that-works-indoors-using-lpg-and/4088
25	Design And Fabrication Of Solar Photovoltaic Sprayer	Solar agro sprayer (sap) is a typical innovative product developed for rural applications which utilizes the solar energy as a fuel. this product is being developed for spraying liquid particles and, pesticides provided with some additional accessories. behind the product, the main heart part is soar panel, which consists of 9 photovoltaic cells, each cell has the capacity of 1 w. this cell converts the light energy from the sun into electrical energy by means of electron hole movements. this solar panel is connected to the 12 v lead acid batteries for storing the electrical energy. a 12 v d.c.motor is connected to these lead acid batteries to convert the electrical energy into mechanical energy. the solar panel can also be connected to this d.c.motor directly, but the difficulty is the force of the spraying will not be as good as running with the aid of battery. hence the need for battery is essential. a blower is attached to this d.c.motor to boost the air for spraying the required purpose.	http://gyti.techpedia.in/project-detail/design-and-fabrication-of-solar-photovoltaic-sprayer/4123
26	Hybrid Solar Cooker for Community	the idea of community solar cooking becomes very important. community solar cooker can cut down the use of conventional energy resources by almost half or even more. we can start saving the energy at home itself. idea has multiple applications. it will be installed in housing society or each of apartment floor where anyone can come and place food items for warming or partial cooking. frugality of idea lies with number of consumers using it every day.	http://gyti.techpedia.in/project-detail/hybrid-solar-cooker-for-community/4224
27	Solar Cooling For Sustainable Energy	Principle of operation the general principle of operation is the production of cold starting from a source of heat. the simplified diagram of operation of the solar cooling technology is the following: solar panels absorb the sun radiation and convert it into water or hot air; the water or hot air	http://gyti.techpedia.in/project-detail/solar-cooling-for-sustainable-energy/5196

		produced by the panels passes through the refrigerating machine, which turns it into water or cold air; the water or cold air is used to cool indoor environments, or for industrial refrigeration.	
28	Solar Electrical Bicycle	A method of upgrades a conventional bicycle over to solar-powered electrical bicycle that is powered by an electric motor which gets its supply from photovoltaic (pv) panels. the pv panels must be mounted and installed at the electric bicycle without compromising riding comfort ability.	http://gyti.techpedia.in/project-detail/solar-electrical-bicycle/5660
29	Solar Powered Hybrid Vehicle for Handicapped/aged Person.	This is a three-wheeler non-polluting vehicle which enables the mechanical transportation of passengers especially handicapped and aged persons without using any conventional fuel. this vehicle uses the unconventional source of solar energy for generation of electric power for driving a motor. the solar system produces current to charge a rechargeable battery which in turn drives the dc electric motors to drive the vehicle. the system has an additional attachment for charging the battery directly with the conventional electric supply as and when needed.	http://gyti.techpedia.in/project-detail/solar-powered-hybrid-vehicle-for-the-handicapped-aged-person/5908
30	Solar Lounge	solar lounge is a portable outdoor all-weather lounge which comprises cushioned seat with backrest for two persons, a solar panel placed at 35 degree, led lights and driving unit placed inside a cabinet. this lounge is self-sustained with the back rest tilted at angle of 70 degree. the structure of the lounge is portable and made of weather proof sun mica. the drive unit includes inverter, rechargeable battery, solar panel which can run a load of about 190 w without any dependence on grid connection.	http://gyti.techpedia.in/project-detail/solar-lounge/5866
31	Solar Powered ATM Machine	Atm machine operation, its lighting and air conditioning collectively considered as the center and here after called atm center. the atm center and goods lending machines are unlimited increasing around the global. all the centers are electrified for their operation, lighting and air conditioning from distribution network.	http://gyti.techpedia.in/project-detail/solar-powered-atm-machine/7166
32	Solar Operated Rotavator	The present research has dealt with solar rotary tiller design for the power tiller that is made for using in primary and secondary tillage.	http://gyti.techpedia.in/project-detail/solar-operated-rotavator-sor/8010
33	Foldable Housing System	The primary objective of foldable houses is to create unique structures which are rapid and cost-effective that can be deployed as an emergency shelter during the times of disasters- natural or	http://gyti.techpedia.in/project-detail/foldable-housing-system/13132

		artificial. It is provided with integrated solar panels	
34	Inno- Village	inno –village is inspired by the jawaharlal nehru national solar mission and digital india with the vision to create a model that has automated irrigation system, green house farming, solar street lights, internet-based farming. this project make the use of clean renewable solar energy to drive the motor for irrigation.	http://gyti.techpedia.in/project-detail/inno-village/12268
35	Lumino Energy Walls	system consists of : dssc coating & solar panels solar panels with solar trackers will be mounted on roof tops & car porch. dssc coating can be attached with the walls (both interior & exterior) the performance of dssc can be improved by altering the doping.	http://gyti.techpedia.in/project-detail/lumino-energy-walls/11735
36	Solar powered oil extraction unit	Grains and nuts are agricultural produce need extraction mill for oil. This facility is conceptualized and developed by using PV power	https://www.flexitron.com/rural-empowerment
37	Solar powered rice hulling machine	The machine produces rice in short time and in quantities sufficient for a family over a week. The operation of the equipment is powered by Solar Energy and helps make it completely power independent.	https://www.flexitron.com/rural-empowerment
38	Solar powered rope spinning machine	A lot of Rice straw, wild banana, and other fibrous products are found in Northeast India. This equipment was Innovated and designed to spin ropes from this yarn. A single person can spin ropes and produce a large quantity of ropes for use in several applications.	https://www.flexitron.com/rural-empowerment
39	Integrated solar powered cooking and lighting unit.	solution was innovated which uses Solar energy to help in forced ventilated cooking and also a small light pack to provide illumination.	https://www.flexitron.com/rural-empowerment
40	Solar cell phone charging station for rural India	This design ensures that irrespective of electricity availability cell phones can be charged for a small fee. The equipment owner also earns a good source of revenue.	https://www.flexitron.com/rural-empowerment
41	Sonic beacon guide for blind.	Navigation and mobility for the blind and visually impaired persons is a major challenge. The visually impaired persons move with the aid of a cane and a lot of other external cues like step count, familiar sounds, ground conditions etc.	https://www.flexitron.com/rural-empowerment
42	Solar battery charger for hearing aid button cell.	The BTE hearing aids are being distributed by the Government of India free of cost to economically weaker section of the population in India but the aid users specially in the rural areas found it difficult to afford the frequent battery replacement cost and many a	https://www.flexitron.com/rural-empowerment

		times its availability was also a major issue. A solar battery charger was designed to solve the issue.	
43	Solar Mosquito Destroyer	This device makes use of the smell from the septic tank to attract the mosquitoes. Once the mosquitoes get trapped inside the device, the heat built up inside the device, as a result of direct sunlight exposure, kills them.	http://nif.org.in/innovation/solar_mosquito/36
44	Solar laminator	This machine gives almost the same output as that of an electricity-operated laminator when sun is hot. Now there is no need to worry about the frequent power losses.	http://nif.org.in/innovation/Solar_laminator/336
45	Pesticide Sprayer Operated by Means Of PV Effect	This project fulfilled the tasks like hand spraying, ic engine spraying, and leg pump spraying etc., using non-conventional energy sources. thus solar operated spray pump will help the farmers of those remote areas of country where fuel is not available easily.	http://gyti.techpedia.in/project-detail/pesticide-sprayer-operated-by-means-of-pv-effect/9428
46	Modified Chulha	The idea is to make a chimney which will work on the solar energy cum potential energy for the village households specially women because due to smoke of the chulha they have to suffer from many respiratory diseases and since it is money consuming so they dont ve to think either of the expenses.	http://gyti.techpedia.in/project-detail/modified-chulha/8137
47	Education Projector	etails about kit kit will have a mini projector which will capable to run on 12 volts. kit will have raspberry pi with external storage in micro sd card. data (videos or jpg) can be loaded to it by micro SD card. it can also get connected to any smart phone and direct that screen of phone can be projected. device can be run with 7 without mobile for teaching purpose. it can have various options of power sources from dynamo to solar rechargeable battery.	http://gyti.techpedia.in/project-detail/education-projector/4771
48	Navjat-phototheraphy Unit	it designed in such a way that it caters the needs of rural health care centers, unburdening national hospitals by rapidly treating mild to severe newborn jaundice in the mother's room during the first weeks of life. our key innovation is providing multiple treatment of neonates from top and bottom therapy in a single unit. other key features are long life, high power leds with energy efficiency (solar cell powered), cost effectiveness by providing state-of-the-art intensive treatment in a compact package.	http://gyti.techpedia.in/project-detail/navjat-phototheraphy-unit/3633
49	Scintilla - A Portable Urine Protein Analyzer	There are around 300 million potential patients, in india alone, who may need urine protein estimation in the diagnosis of the disease, monitoring the progress of the disease, rating the severity of the disease, patient's response to the	http://gyti.techpedia.in/project-detail/scintilla-a-portable-urine-protein-analyzer/3124

		therapy, planning the future course of treatment for the patients etc.	
50	Automatic Fodder Feeding System For Cattle	he design requires the fodder/bran storage container, the water reservoir container, motors, pumps, a mixing unit and the feeding tray. a dedicated phone will be required for controlling the system remotely, a solar panel and a battery for powering the system. the entire system will work on 12 volts and 5 volts. the system will start when the cattle owner dials the phone number of the phone attached to the system and dials a pre configured code. the codes for feeding and wash-drain are different to allow separate operations as required.	http://gyti.techpedia.in/project-detail/automatic-fodder-feeding-system-for-cattle/199

Appendix IV

PROTEK INSTRUMENTS PVT. LTD.

PROTEK INSTRUMENTS

**102, Vidyanagar-7, ManMandir Appt., Katraj - Kondhwa Road,
Pune- 411046 Tel.: 9975627360 / 7775812286**

Date: 20.01.2022
Subject: No Objection Certificate and Consent Letter

TO WHOMSOEVER IT MAY CONCERN

This letter is issued to provide consent and information that Protek Instruments Private limited is a private organization operating in the design, development and marketing of electronic solutions, including solar photovoltaic solutions, electronic data loggers, solar PV powered tests rigs and electric vehicle-related solutions.
At the request of Mr Pranav Ashok Satpute (PhD research scholar of Department of Design, IIT Guwahati), Protek instruments voluntarily participated in the research study. There is no objection from Protek Instruments Private Ltd. to publishing this research study on any national and international platform. Also, Protek Instruments Private Ltd. do not impose any copyright and commercial bonds on the conducted research and developed solutions.

From Protek Instruments Pvt Ltd.

Mr Akshay Horane
Director,
Protek Instruments Pvt. Ltd. Pune

Appendix V

PIPV Product Assessment (PIPV उत्पादन मूल्यांकन)

Product Evaluation on Spiderweb assessment model (स्पायडरवेब असेसमेंट मॉडेलवर उत्पादनाचे मूल्यांकन)

1. Usability - Is product easy to understand and use correctly? (उपयोगिता - उत्पादन समजून घेणे आणि योग्यरित्या वापरणे सोपे आहे का?)

Mark only one oval.

	1	2	3	4	5	
No (नाही)	⬭	⬭	⬭	⬭	⬭	Yes (होय)

2. Functionality - Does the Product live up the manufacturing claim ? has it been well engineered? (कार्यक्षमता - उत्पादन उत्पादनाच्या दाव्यानुसार आहे का? ते तांत्रिकदृष्ट्या चांगले कार्यान्वित केले गेले आहे का?)

Mark only one oval.

	1	2	3	4	5	
No (नाही)	⬭	⬭	⬭	⬭	⬭	Yes (होय)

3. Desirability - Is product aesthetically attractive to the user? (वांछनीयता - उत्पादन वापरकर्त्यासाठी सौंदर्यदृष्ट्या आकर्षक आहे का?)

Mark only one oval.

	1	2	3	4	5	
No (नाही)	⬭	⬭	⬭	⬭	⬭	Yes (होय)

Contd.

4. Affordability - Is the product within price range of local people or can it be purchased using loan? (परवडणारी क्षमता - उत्पादन स्थानिक लोकांच्या किंमतीच्या मर्यादेत आहे किंवा ते कर्ज वापरून खरेदी केले जाऊ शकते?)

Mark only one oval.

	1	2	3	4	5	
No (नाही)	◯	◯	◯	◯	◯	Yes (होय)

5. Acceptability - Is the product culturally suitable? (स्वीकार्यता - उत्पादन सांस्कृतिकदृष्ट्या योग्य आहे का?)

Mark only one oval.

	1	2	3	4	5	
No (नाही)	◯	◯	◯	◯	◯	Yes (होय)

6. Durability -Is the product capable to sustain surrounding factors? (टिकाऊपणा - उत्पादन आसपासच्या घटकांसह टिकून राहण्यास सक्षम आहे का?)

Mark only one oval.

	1	2	3	4	5	
No (नाही)	◯	◯	◯	◯	◯	Yes (होय)

Contd.

7. Reparability - can the product be maintained and repaired by local tradesmen without the need for significant skills or imported components? (पुनरुत्पादनक्षमता - महत्त्वपूर्ण कौशल्ये किंवा आयात केलेल्या घटकांशिवाय स्थानिक व्यापाऱ्यांनी उत्पादनाची देखभाल आणि दुरुस्ती केली जाऊ शकते का?)

Mark only one oval.

	1	2	3	4	5	
No (नाही)	⬭	⬭	⬭	⬭	⬭	Yes (होय)

8. Affinity - Is the product something users will be proud to own and take care of ? (आत्मीयता - असे उत्पादन आहे का जे वापरकर्त्यांना स्वतःच्या मालकीचे आणि काळजी घेण्यास अभिमान वाटेल?)

Mark only one oval.

	1	2	3	4	5	
No (नाही)	⬭	⬭	⬭	⬭	⬭	Yes (होय)