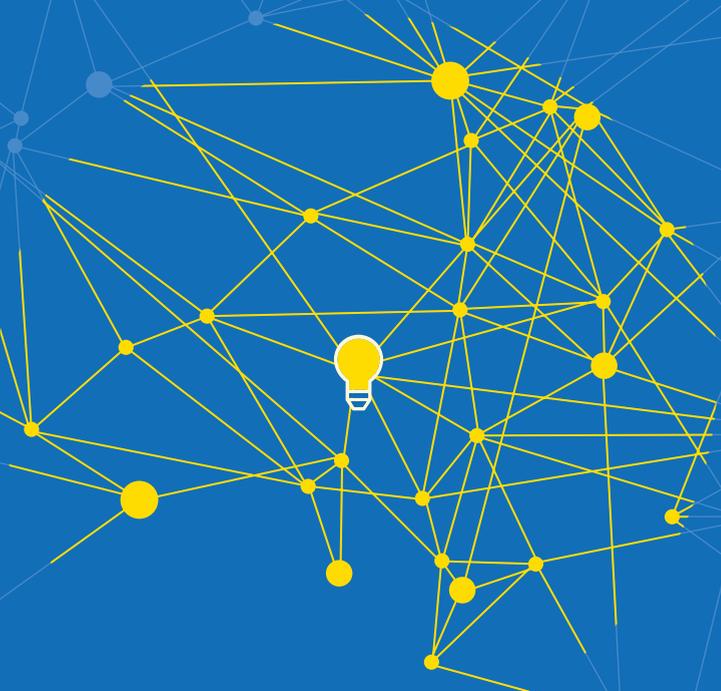


# A SYSTEMS DESIGN APPROACH TO SUSTAINABLE DEVELOPMENT

Embracing the complexity of energy  
challenges in low-income markets





# Summary

The societal and technical problems faced by low-income markets are increasingly seen as more complex due to environmental, social, and economic concerns. The enormous negative impacts of societal problems and the inability of designers to deal with complexity cannot be overcome without a paradigm shift in how we understand, engage with, and teach about such issues. In light of this challenge, one can pose the question, “*What is the best approach to deal with a complex societal problem?*”. A traditional approach to deal with a complex problem is to simplify it. Alternatively, as here, research may aim to provide a novel approach to handle complex societal problems, thereby embracing complexity. Thus, this research contends that embracing complexity represents a significant shift from the traditional design approach to a systems design approach for sustainable development.

The thesis focusses on theories and practices that are central and relevant to the debate on sustainability and systems thinking in design. It aims to foster designers’ understanding of sustainability issues, like energy challenges in low-income markets, to contribute, through design, to solving complex societal problems. For this reason, the investigation focusses on those low-income energy markets which are particularly sizeable in emerging economies in Latin America and Africa. Generally speaking, low-income energy markets lack access to affordable, reliable, clean, and modern sources of energy, which results in pollution, health problems, and high electricity costs, amongst other issues.

Low-income energy markets represent a favourable opportunity to satisfy demand in alignment with sustainable development goals. Nevertheless, designers have struggled to support low-income communities to improve their living standards by providing sustainable energy solutions. Consensus exists that without access to sustainable energy products and related services, sustainable systems cannot be created and sustainable development cannot be achieved. However, complex societal problems in low-income energy markets are far from obvious, and solutions to these problems are far from optimal. Such problems are often very hard to define due to limited availability of information about the problem situation and the lack of context-specific knowledge. Nonetheless, these are problems that impact everyday life in low-income contexts.

While complex problems may involve high levels of technical complexity, the term *complex societal problems* adopted in this thesis refers to complex problems where technical complexity is entangled with societal complexity, and where relations among humans and institutions are central to the solution. Moreover, the concept of complexity adopted here also refers to the lack of knowledge of the characteristics of the system in place, the lack of understanding of the problem situation at hand, and the lack, or uncertainty, of the expertise needed to handle the problem. This investigation suggests that the integration of systems

thinking and design is a promising approach to address the increasing complexity of societal problems. The central research question proposes to gain insights into systems-oriented approaches to design (also referred to here as a systems design approach). In particular, I focus on systems approaches and methodologies to develop product-service systems for complex societal problems, such as those encountered in low-income energy markets.

A Product-Service System (PSS) consists of a system of products, services, supporting networks, and infrastructures which closely involve multiple stakeholders who offer functionality, utility, and satisfaction (Mont, 2002a). For many authors, the adoption of systems thinking on PSS is fundamental for a proper conceptualisation and in-depth understanding of the system in place (Afshar & Wang, 2010; Cavalieri & Pezzotta, 2012). In this context, this thesis contributes to PSS and systems design research by addressing the need for the expansion of the scope of PSS from its focus on a separable system of product-service combinations towards a whole PSS system capable of handling complex societal problems.

To this end, this doctoral research investigates systems theory and practice to understand the implications of systems thinking for design and offers recommendations for the adoption in design approaches, such as PSS design. The investigation is based on the hypothesis that the difference between traditional design approaches and systems design approaches lies in their underlying assumptions regarding the boundaries and scope of design. In other words, the latter strive to achieve a holistic, multilevel, and pluralistic perspective that embraces the complexity within the system in place. Based on the problem definition, the central research question and sub-questions are proposed as follows:

**MAIN RESEARCH QUESTION:**

*MRQ. How can systems thinking contribute to handling the complexity of sustainable product-service system design for low-income energy markets?*

RESEARCH STRATEGY		RESEARCH SUB-QUESTIONS
<p><b>THEORETICAL PHASE</b> (Chapter 2)</p>		<p><b>RQ1.</b> What are the characteristics of complex societal problems in low-income energy markets?</p> <p><b>RQ2.</b> How has systems thinking been developed as a way of handling complex societal problems?</p> <p><b>RQ3.</b> To what extent does systems thinking provide the best fit to the design of solutions aimed at complex societal problems?</p>
<p><b>EMPIRICAL PHASE</b></p>	<p><b>Observations of Existing Practice</b> (Chapter 3)</p>	<p><b>RQ4.</b> What does the adoption of systems thinking as a multilevel perspective tell us about improving energy solutions in low-income energy-efficiency programmes?</p>
	<p><b>Interventions in Design Education</b> (Chapters 4-5)</p>	<p><b>RQ5.</b> How can systems thinking support design students in the development of more sustainable product-service system (PSS) concepts for low-income markets?</p> <p><b>RQ6.</b> How can the capacity for design students to respond to the complexity of societal problems, such as those found in many low-income markets, be built?</p>

Within the research structure seen above, the thesis comprises four primary studies (Chapters 2-5) published as peer-reviewed journal articles. Each publication addresses one or more sub-questions that support the answer to the main research question. It should be noted that the chapters do not reflect the chronological publication of the articles. Consequently, the knowledge creation has not been linear (e.g., a chapter might not entirely build upon the knowledge from the previous study). Nevertheless, the findings from each study come together to provide contributions to three main design areas: theory (Chapter 2), practice (Chapter 3), and education (Chapter 4-5).

## **Theoretical Phase**

### *Preliminary Research*

The preliminary research of this investigation is reported in Chapter 1. The first chapter introduces the rationale for the investigation. It recognises some of the limitations of using traditional design approaches to gain an understanding of complex societal problems in low-income energy markets. Moreover, it argues that a more holistic approach can be taken to complement the reductionist nature of traditional scientific methods adopted in design. Additionally, it points out that the potential to trigger radical changes in technological and socio-cultural terms lies in design approaches that consider the capacity of design to handle complexity. Besides, it focusses on energy solutions that integrate products, services, and infrastructure to offer satisfaction through better system functionality and utility.

Furthermore, Chapter 1 indicates that sustainable product-service systems (PSS) provide an opportunity to satisfy energy demand in low-income markets with solutions that are compatible with sustainable development. It demonstrates why developing sustainable product-service systems for low-income energy markets are imperative for developing and emerging economies that aim to reconcile socio-economic development with environmental protection. The preliminary literature review provides evidence that PSS is a promising concept for stimulating sustainable generation, distribution, and consumption of energy.

The results in Chapter 1 imply that however promising, PSS is often bound to fail in low-income markets due to the particular societal complexity existing in low-income contexts. In this regard, the chapter demonstrates how systems thinking can advance product-service systems for low-income energy markets. The chapter concludes that to develop more sustainable energy solutions in low-income markets, problem-solvers need to increase complexity-handling capacity by adopting four major systems thinking tenets: a holistic perspective; a multilevel perspective; a pluralistic perspective (diversity of views); and complexity-handling capacity.

### *Theoretical Research*

The preliminary research in Chapter 1 suggests that systems thinking can advance energy solutions for low-income markets. In Chapter 2, the adoption of systems thinking in design is explored to highlight some implications of using a systems design approach for addressing complex societal problems. Chapter 2 aims to provide a systems thinking foundation for the investigation; this was developed by drawing on knowledge from all chapters. The primary goal of the chapter is to foster understanding of the implications of systems approaches and methodologies and explore the adoption of systems thinking tenets in design.

The chapter demonstrates that the underlying assumptions and tenets of systems thinking provide a valuable corrective to reductionism when using a traditional scientific method to tackle complex societal problems. An extensive literature review outlines significant aspects

underlying systems thinking; appropriate systems approaches and methodologies are identified, and their contributions to handling complex societal problems in the field of design are clarified. Previous studies have attempted to explore the field of systems thinking to offer recommendations for how to apply systems methodologies and tools in design. However, little attention has been paid to how designers have interpreted and employed systems methodologies and tools to tackle complex societal problems.

Chapter 2 investigates the process of integrating systems thinking into design and provides an overview of the emerging field of a systems design approach to complex societal problems. It summarises the current state-of-the-art by describing how a selection of existing systems design approaches has provided significant contributions to the transition from a traditional design approach to a systems-oriented perspective in design. Based on these theoretical insights, the chapter emphasises the opportunity to develop systems design approaches further through the systematically and informed exploration of systems thinking. The study results in a conceptual framework that offers criteria for the integration of systems thinking into design. Accordingly, the main contribution of the study is to provide a framework that allows for developing new, and strengthening existing, systems design approaches by supporting designers to further realise the resources of systems thinking on which they can draw.

### **Empirical Phase**

#### *Observations of Existing Practices*

Chapter 3 investigates the adoption of systems thinking as a multilevel perspective to gain a better understanding of the constraints imposed by the complexity of energy challenges in low-income energy-efficiency programmes in Brazil. Brazil is selected for this empirical study because it presents many relevant energy challenges that require urgent attention. Building on design theory grounded in systems thinking, three aggregation levels of the Brazilian low-income energy market are analysed to gain insights which are useful for the design of sustainable energy solutions. The chapter examines findings from the literature, descriptive cases, and interviews with practitioners and experts.

Previous studies have shown that, although fundamental, improvements at a technological level are limited in the creation of sustainable energy transitions. For this reason, to tackle energy challenges in low-income markets, it is necessary to move from technological improvements alone to a broader societal perspective that takes into consideration organisational and societal transformation, which implies high levels of societal complexity. This study contributes to uncovering knowledge about the complexity of low-income energy markets and to realising implications of a multilevel analysis for energy solutions. Also, it demonstrates that such knowledge is valuable to the redesign of low-income energy programmes and to inform new policy development or policy revisions.

Results show that adopting a multilevel perspective in low-income energy-efficiency programmes allows policymakers and problem solvers to identify relevant constraints and opportunities across system levels. More specifically, a multilevel analysis uncovers key aspects hindering energy solutions in low-income energy programmes to achieve higher levels of sustainability. In addition, it produces insights for recommendations to improve the current situation. Understanding and overcoming social and technical challenges hindering energy solutions is crucial for increasing the ability of energy programmes to achieve higher levels of socioeconomic benefits and lower environmental impacts on low-income communities.

The findings suggest that a systems design approach requires designers to handle a more substantial degree of complexity in comparison to other traditional approaches. Consequently, they must be equipped with a set of systems-oriented knowledge, skills, and tools, appropriate to deal with this new reality. To face this significant challenge in design education, the last two chapters of the thesis address, and so contribute to, support for the development of capacity building for a systems design approach.

#### *Interventions in Design Education*

As designers are typically educated to apply traditional design approaches, higher education institutions become an essential agent for change. Therefore, the interventions carried out in Chapters 4 and 5 explore the application of a systems design approach to design product-service systems concepts by students. The interventions allowed the research hypothesis and the theoretical model presented in Chapter 3 to be tested. Further, they provided an initial exploration of the conceptual framework described in Chapter 2.

The intervention in Chapter 4 provided an exploratory exercise in which to apply a systems design approach by students from Delft University of Technology (the Netherlands) to create product-service system concepts to identify advantages and disadvantages in this process. In Chapter 5, design students familiar with low-income energy markets tested a systems design approach to solve energy challenges faced by low-income communities in Uganda. This concluding intervention builds upon the previous chapter and seeks to gain a better understanding of the process of learning a systems design approach and the means to support that learning in design.

Chapter 4 reports a Master's course called "Product-Service System" that applies systems thinking in the development of sustainable product-service system concepts for complex societal problems. The chapter explores higher education institutions as a base for knowledge transfer between multiple stakeholders when addressing the need for affordable energy in low-income households and the implementation of humanitarian aid. In this study, multidisciplinary student teams from TU Delft (the Netherlands) use knowledge and skills based on System Oriented Design and PSS to develop twelve PSS concepts. The study was

conducted in collaboration with the Federal University of Paraná (and partners) in Brazil, and the Innovation Unit of *Medécins Sans Frontières* (Doctors Without Borders) in Sweden. For this reason, the study's scope was extended to address the context of humanitarian aid.

The empirical data used in Chapter 4 emerge from a set of PSS concepts targeted for low-income contexts, conducted by student teams on a multidisciplinary course. Based on the design activities carried out by students and the outcome of the projects, advantages and the context- and process-related challenges of using systems thinking are presented and discussed. The findings demonstrate that a systems design approach provides students with comprehensive knowledge and skills to deal with complex societal problems. However, there remains the need to introduce appropriate systems resources (e.g., systems strategies and tools) in the current design curriculum, making the transition from a traditional design approach a challenging one. The findings imply the need for the further development of systems-oriented competencies in design students.

Chapter 5 describes a Master's course called "System Design for Sustainable Energy for All". The course proposes to develop and test teaching resources based on systems thinking and promote capacity building for a systems design approach. Ugandan design students, from the College of Engineering Design Art and Technology at Makerere University, familiar with the local context, adopt a systems design approach to solve energy challenges faced by low-income communities in Uganda. The chapter suggests key competences for skilful performance when designing product-service system concepts aimed at low-income energy markets and demonstrates the process of applying such competences. The previous chapter (Chapter 4) provides background information, which helps to develop the building blocks of a new set of knowledge, skills, and tools for addressing complex societal problems. Chapter 5 narrows the scope of the study to focus on building capacities to apply systems thinking in the development of sustainable energy PSSs.

In addition, key cognitive aspects of capacity building for a systems design approach is provided for educators. Moreover, the chapter demonstrates the process of embedding systems thinking into the course curriculum to support students in the development of sustainable solutions for low-income energy markets in Uganda. The findings support that design approaches grounded in systems thinking can help to deal with the increasing complexity of the societal problems that future generations of design professionals are expected to solve. Therefore, a significant contribution of the study for design education is to propose key competencies to address gaps in capacity building for complexity in design.

## Reflection Phase

*Main findings, contributions, and recommendations*

Chapter 6 provides a general summary of the main findings to emerge from the thesis. Contributions to design theory, education, and practice are presented. The four main contributions provided in this research are:

- Exploring the integration of systems thinking into design, particularly by adopting a systems design approach to sustainable energy solutions for low-income markets.
- Extending the scope of product-service system design through the introduction of four major systems thinking tenets: a holistic perspective; a multilevel perspective; a pluralistic perspective; and complexity-handling capacity.
- Proposing heuristic tools for the integration of systems thinking into design, which allows for developing new and strengthening existing systems design approaches.
- Increasing capacity building for a systems design approach to address complex societal problems through design education.

The chapter contends that designing sustainable energy solutions for low-income markets requires effective interventions capable of handling high levels of societal complexity. To do so, the adoption of a systems design approach in addition to the traditional reductionist approach is required. This means embracing the complexity within societal problems, systems or contexts, and employing new thinking and skills to handle such complexity.

**Keywords:** Design for sustainability, complex societal problem, systems thinking, systems design approach, systems-oriented design, product-service system, low-income market, energy solution.

ISBN 978-94-6384-102-3



9 789463 841023

The societal and technical problems faced by low-income markets are increasingly seen as more complex due to environmental, social, and economic concerns. The enormous negative impacts of complex societal problems and the inability of designers to deal with complexity cannot be overcome without a paradigm shift in how we understand, engage with, and teach about such issues. In light of this challenge, one can pose the question, “What is the best approach to deal with a complex societal problem?”.

A traditional approach to deal with a complex problem is to simplify it. Alternatively, as here, research may aim to provide a novel approach to handle complex societal problems, thereby embracing complexity. Thus, this book contends that embracing complexity represents a significant shift from the traditional design approach to a systems design approach for sustainable development. To help designers to bring about such a transition, the four main contributions provided in this doctoral research are:

- Exploring the integration of systems thinking into design, particularly by adopting a systems design approach to sustainable energy solutions for low-income markets.
- Extending the scope of product-service system design through the introduction of four major systems thinking tenets: a holistic perspective; a multilevel perspective; a pluralistic perspective; and complexity-handling capacity.
- Proposing heuristic tools for the integration of systems thinking into design, which allows for developing new and strengthening existing systems design approaches.
- Increasing capacity building for a systems design approach to address complex societal problems through design education.