Designing a Digital Platform for Carbon Credit Issuance

Multi-Actor Information System Architecture Design, Facilitating the Issuance of Carbon Credits and Compensation for Clean Cookstove Users

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by

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to obtain the degree of Master of Science in Complex Systems Engineering and Management (CoSEM)
Faculty of Technology, Policy and Management at the Delft University of Technology,
to be defended publicly on Tuesday, October 31, 2023

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Cover: Clean cookstove receivers in Rwanda, FairClimateFund (Modified)

TU Delft

Preface

I sincerely want to express my profound appreciation to my dedicated and insightful supervisors, Dr. Y. (Aaron) Ding, E. (Ellen) van Andel, and N. (Neera) van der Geest. Your unwavering support, guidance, and encouragement have been pivotal in shaping the course of this research. A special word of gratitude goes to Dr. J. (Jolien) Ubacht, whose tireless dedication is immeasurable. Jolien, you invested countless hours in meetings with me, meticulously reviewed my thesis, and provided invaluable input that elevated this work's quality.

I thank the FairClimateFund for their support, trust, and collaboration. Their commitment to sustainability and their belief in the potential of this research has been a driving force behind my work.

I am deeply grateful to the interview partners who generously shared their insights, knowledge, and experiences, enriching this thesis in various ways. Your contributions have been invaluable, and I am indebted to you for your time and expertise.

My family, particularly my mother, has been a constant source of love and encouragement. Your unwavering belief in me has been my anchor throughout this academic journey. I am also incredibly grateful to my partner, Katharina, for her support and understanding during the demanding phases of this thesis.

This master thesis is a culmination of the collective efforts, support, and belief of many. I hope it contributes meaningfully to the field of research and projects aiming for a more sustainable future. Thank you to everyone who has been a part of this journey, and I hope this work reflects the trust and confidence you have placed in me.

Sophian Beyerlein
Delft, October 2023

Executive Summary

The primary goal of this research is to develop an innovative information system architecture for streamlining the awarding of carbon credits and compensating clean cookstove users. Focusing on Rwandan households transitioning from conventional biomass burners to more efficient cookstoves, the project seeks to promote healthy cooking practices and reduce carbon emissions.

Academic research has lacked a specific information system design to directly monitor emission reduction at the source to award carbon credits efficiently. This research proposes a solution that includes distributing clean cookstoves and creating a digital platform to facilitate carbon credit recording and distribution, along with an integrated payment mechanism. The information system architecture plays a pivotal role in scaling sustainable cooking projects and combating climate change.

To address the research question, "What is a possible design for a digital multi-actor platform for the issuance of carbon credits?" a hybrid approach integrating Peffers's design science research framework and a system engineering methodology is employed. The study comprehensively analyses the Rwandan context, identifying 15 functional and 22 non-functional requirements for the system. A functional and logical system architecture is then presented with detailed interfaces. The system architecture's evaluation includes verifying functions and logical system elements against requirements and validating the system through expert interviews.

This research fills a gap in the literature by offering a systematic design cycle for tailored information systems in clean cooking projects, aiding stakeholders in context analysis, requirements elicitation, and system architecture design. It introduces an architecture valuable to information systems researchers and practitioners, especially in sustainable finance projects. The design cycle is a practical guide through various development stages, facilitating comprehension of essential requirements. These findings benefit researchers delving into information system design for clean cooking and sustainable finance initiatives. Furthermore, the adaptable system design provides a valuable resource for the FairClimateFund and related initiatives, supporting the adoption of information systems and issue resolution in sustainable finance, furthering the sustainability agenda.

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Acronyms

ERP Enterprise resource planning. 23

FCF FairClimateFund. 4–7, 9, 14–19, 21–24, 28, 29, 31, 32, 40, 42, 67, 68, 71–73, 80, 89

GHG Greenhouse Gas. 21, 24

MRV Measurement, recording and verification. 18, 19

SOI System of interest. 14, 16, 18–32, 34, 40, 41, 53, 60

1 Introduction

1.1. Problem statement

Climate change is one of society's biggest challenges in the 21st century. Human activities have led to a change in climate, concerning researchers in various domains (Botta et al., 2019)(Abbass et al., 2022). Legacy systems, such as energy systems and, therefore, the burning of fossil fuel, agriculture, deforestation, and land use changes such as urbanization, have all contributed to a rise in greenhouse gases in our atmosphere. Researchers have highlighted the importance of greenhouse gas reduction for many years now (Monteiro et al., 2022). However, the issues have become more and more relevant. Recent events such as heat waves, floods, droughts, and mass extinctions have led to a public understanding of the issue (Zuazua Ruiz et al., 2023). The broader realization of climate change-related issues led to the Paris Agreement under the United Nations Framework on Climate Change in December 2015 (Kreibich & Hermwille, 2021). The Paris Agreement acknowledges climate change as a global emergency and highlights that it is a borderless issue requiring international cooperation. The long-term goals to guide all nations are comprised of three main points (United Nations, 2015):

- substantially reduce global greenhouse gas emissions to limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees;
- review countries' commitments every five years;
- provides financing to developing countries to mitigate climate change, strengthen resilience and enhance abilities to adapt to climate impacts.

The global drive to reduce carbon emissions has been on the rise. 197 countries have joined the Paris Agreement (Lee et al., 2023). This has led to an increase of major companies pledging to achieve net zero emissions (Kreibich & Hermwille, 2021). Most of these companies rely on the compensation of remaining emissions through offsetting. This is directly linked to the goals mentioned above. The offsetting of carbon emissions in its most popular form is realised through carbon credit issuance systems (Anjos et al., 2022). Emission trading, which involves issuing carbon credits, is a market-based approach to control pollution by creating economic incentives to reduce carbon emissions. Within the voluntary emission trading market, one approach is setting up systems enabling climate adaptation in Low- and middle-income countries (Kreibich & Hermwille, 2021). Markets for carbon credits are introduced as an important component of international efforts to fight climate change. By giving measurable value to reductions in carbon emissions, they offer a way to reward and motivate environmentally conscious behaviour. Their goal of making it easier for businesses to trade and buy carbon credits, they try to aid in the shift to a low-carbon, sustainable future (Ji et al., 2018). It is clear that economics, environmental responsibility, and policymaking interact dynamically in this intricate and dynamic context. Advocates of carbon credit markets emphasise how they can lower greenhouse gas emissions by providing affordable solutions, backing carbon offset projects, and rerouting funds to renewable energy and conservation efforts. Critics, however, have also expressed concerns, pointing up issues such as potential gaps and the possibility of ”greenwashing” techniques that could compromise these markets' ability to reduce emissions significantly (Wara, 2007). The critics contend that voluntary carbon credit markets often lack robust oversight and standards, making it difficult to ensure real emissions reductions and that they are seen by some as potentially providing a false sense of sustainability without driving significant changes in emissions-intensive sectors. The basic idea of these systems is that projects to reduce carbon emissions in developing countries are funded by companies purchasing carbon credits. Therefore, the profit generated from these sales reduces worldwide carbon emissions through the principle of sustainable finance (United Nations, 2015). For this research, the term ”sustainable finance” is used as follows: ”Sustainable finance is defined as investment decisions that take into account the environmental, social, and governance (ESG) factors of an economic activity or project.” Delimatsis (2021). A financial tool used to represent a decrease in greenhouse gas emissions is carbon credits (Betz et al., 2022). Clean cooking projects seek to lower emissions by promoting cleaner and more effective cooking technologies. To reduce emissions and ensure the financial viability of the switch to cleaner cooking solutions, sustainable finance can play a crucial role by sponsoring these initiatives in return for carbon credits. Projects in developing countries, such as the switching from fossil fuels to renewable or less harmful emissions, ultimately lead to an overall reduction of carbon emissions. The difference between previous emissions and those after project implementation is calculated and certified by a third party according to a standard. One carbon credit is issued per reduced tonne of carbon dioxide. Companies and consumers can purchase these credits to offset their carbon emissions, reducing them in different locations (Gill-Wiehl et al., 2023). There are two main methods for reducing and mitigating carbon emissions by means of trading: mandatory and voluntary carbon markets. Certain organizations or sectors must comply with predetermined emission reduction targets under mandatory carbon markets created by governmental rules or international agreements (Anjos et al., 2022). The inability to accomplish these targets is often punished by fines or other enforcement actions. Mandatory carbon markets offer an organized system for reducing emissions, complete with standards and procedures for compliance. Voluntary carbon markets function on a voluntary basis, allowing businesses or people to decide whether to take part and voluntarily reduce their carbon emissions. Participants in these markets may voluntarily compensate emissions for ethical, social, or public relations reasons even when they are not required to do so by law (Bayon et al., 2012).

However, carbon offsetting projects have come under criticism recently for various reasons. Offsetting projects are complex due to the contextual differences and multiple involved actors, which leads to a few challenges that also lay the foundation for the mentioned criticism. The core idea of carbon credit issuance is to finance projects that could not have been executed without the financial support of carbon credits, called additionality (Michaelowa et al., 2019). This requires strict pre-project analysis of the project context and is one reason for the lack of automation and, therefore, the considerable efforts regarding resources and time in establishing and running offsetting projects (Schneider et al., 2019). Despite these efforts, there often is doubts if the additionality of offsetting projects is given (Michaelowa et al., 2019). Another area for improvement is the verification and monitoring procedure of these projects. Stakeholders such as governmental institutions, buyers, and sellers of credits all require accurate and credible information on the issued carbon credits (Woo et al., 2021b). The information on emission reduction relies on different methods, such as measurement and calculations. Many offsetting projects are based in rural and developing countries, which is a result of the greatest potential for net emission reduction due to the vast reliance on fossil fuels for energy generation and cooking in these countries (Wang & Corson, 2015). Since many offsetting projects therefore aim for rural areas and developing countries, the ability to track and verify these procedures is often limited due to a lack of well accessible infrastructure and often remotely located projects sites (Ventrella & MacCarty, 2019). These limitations and recent publications on that topic have resulted in a lack of trust in the system for carbon credit issuance (Gill-Wiehl et al., 2023). While measurement and verification are challenging, the verification process also requires standards to verify against. There certainly are various standards in place that enable the verification. However, using different standards, as the voluntary market does, makes these incomparable or at least makes comparability challenging. Organizations such as *"Gold Standard"*, a private organization certifying carbon credits, have called for uniform standardization of carbon credit issuance (Gill-Wiehl et al., 2023). Uniform standards would make carbon credits more comparable and enable other certification agencies and trusted entities to certify carbon credits and, therefore enable voluntary offsetting projects to scale faster. The issues within the voluntary carbon credit market mentioned earlier, including challenges, namely, additionality, measurement, verification, and lack of standardization, lead to significant concerns by researchers regarding the over-crediting of offsetting projects. Over-crediting refers to challenges leading to wrongfully issued carbon credits (Schneider et al., 2019).

The over-crediting of offsetting projects undermines the original initiatives. A recent publication which at the time of this research has not been peer-reviewed yet, analyzing different methodologies for issuing carbon credits, mentioned over-crediting by these methodologies from 1.3 to 6.3 (Gill-Wiehl et al., 2023). In simpler terms, these values stand for the issuance of up to 6.3 carbon credits despite only one carbon credit should have been rightfully claimed. The various challenges in the multi-actor scenario of carbon credit issuance processes have to be analyzed and improved to comply with the goals defined for reaching the Paris Agreement. The voluntary carbon market refers to selling and exchanging carbon credits outside regulated carbon markets.

An illustrative instance pertains to the quantification of carbon emissions stemming from air travel, with a subsequent commitment to finance environmentally beneficial endeavours, such as reforestation or renewable energy projects, to neutralize the associated carbon footprint. For example, in aviation, individuals allocate resources to initiatives to reduce an equivalent volume of greenhouse gases, thereby contributing to the global effort to combat climate change. This proactive approach empowers individuals to take responsibility for the environmental repercussions of their journeys and extend support to initiatives to offset such impacts (Lu & Shon, 2012).

Individuals, organizations, and businesses voluntarily acquire carbon credits in this market to offset their carbon emissions. The voluntary carbon credit market allows companies in the non-regulated market to take voluntary action to mitigate climate change (Michaelowa et al., 2019).

1.2. Problem context definition

1.2.1. FairClimateFund

The FairClimateFund(FCF), which is the commissioning party of this research, is an organization that promotes sustainable development and combats climate change through various programs. With a strong emphasis on clean energy solutions, the organization has been actively supporting clean cooking projects to lower carbon emissions. The organization hopes to develop better cooking habits, reduce deforestation, and reduce indoor air pollution by tackling the issues associated with traditional cooking practices, particularly in low-income communities. The FCF-supported clean cooking programs centre around distributing and marketing clean cookstoves as an alternative to traditional biomass burners. These cookstoves use advanced technology like electricity, gas or pellets to assure fuel efficiency and considerably lower carbon emissions. The main objective of the FCF's clean cooking initiatives is to offer a simplified method for allocating carbon credits and rewarding people who switch to clean cookstoves. The initiative intends to simplify the recording and distribution of carbon credits based on emissions reductions realized via the use of clean cookstoves by using an innovative information system architecture and digital platform. This strategy ensures that households are fairly compensated by receiving the compensation of issued carbon credits, which encourage using clean energy sources and sustainable cooking techniques. The FCF offers the issued credits on the previously mentioned voluntary carbon credit market. Their objective is to fully funnel back the revenues after the subtraction of costs to the communities, which reduce their carbon emissions (FairClimateFund, n.d.).

1.2.2. Problem context

After clarification of general challenges in carbon offsetting projects and the introduction of the problem owner of this research, it is vital to highlight the project-specific problem context. Clean cooking projects, in which traditional biomass burners for cooking are exchanged with alternatives that emit fewer carbon emissions, are not only prone to the previously mentioned general challenges. Furthermore, These projects are challenged by local regulations, social influences, and technical difficulties typical for complex socio-technical systems. Local regulations were explored and considered for this research. Social influences, such as lack of awareness, acceptability of clean cookstoves, and others, differ depending on regional context; these must be explored in the research. The technical aspect of the project also imposes context-specific challenges. Through various different projects, the primarily remotely located communities provided with clean cookstoves deal with power shortages, limited infrastructure such as network coverage, and lack of maintenance services for such devices. The infrastructure for fuel delivery in the case of non-electric stoves also needs to be analyzed next to others. Overall these context-specific factors will have a fundamental influence on the system design (Bisaga & To, 2021).

The contextual variables and socio-technical aspects presented in this section will be a subject of the research. In addition, the FCF and recent publications have identified specific challenges, which are determined improvable by the design of an information architecture (Woo et al., 2021a). The commissioning party of this research has highlighted the following challenges through experience in the sector and previously conducted research:

- **Duration of certification processes**: Carbon credit generation takes two to three years and depends on long processes of (manual) data collection. Monitoring, reporting and verification are done through external auditing parties. These external procedures are costly and stagnant (N. Van der Geest, personal communication, April 18, 2023)(Harrell et al., 2016).
- **Cost of registration**: The registering of carbon credits takes approximately 5 per cent of the cost of a credit. The costs for registration are especially high for micro-scale projects (N. Van der Geest, personal communication, April 18, 2023).
- **Assumptions on cookstove usage**: The certification methodologies used for the calculation of carbon credits to be issued mostly rely on assumptions on cookstove usage. The lack of accuracy imposed by assumptions, has led to certification agencies and researchers exploring options for real-time monitoring of cookstoves (N. Van der Geest, personal communication, April 18, 2023)(Harrell et al., 2016)(Gill-Wiehl et al., 2023).
- **Lack of transparency**: Carbon credits currently lack the information on which involved party benefits and to what extent. The credits are issued on a project-based approach without full information on the producer of the credits. Project developers have to cover their costs. However, the information on financial asset distribution is not disclosed to the public in most cases (Wang & Corson, 2015). In addition, the intent of a sustainable finance project is the achievement of environmental objectives, which should be made visible by improving the traceability of credits and therefore ensuring transparency (N.

Van der Geest, personal communication, April 18, 2023)(United Nations, 2015)(Kreibich & Hermwille, 2021).

The challenges mentioned by the research commissioner and various publications on cooking projects introduce an information architecture as a possible solution for the improval of current carbon credit issuance systems (N. Van der Geest, personal communication, March 14, 2023)(Woo et al., 2021b)(Kreibich & Hermwille, 2021)(Ventrella & MacCarty, 2019). Another publication by Bisaga and To (2021), suggest the usage of different funding and delivery models for cooking services. The suggested payment mechanism by the FCF seems to be coherent with that and will be part of the information architecture design.

2
Research approach

The following research question is formed by a combination of the original problem statement given by the FCF, including the mentioned challenges in the previous section, and desktop research of academic literature concerning clean cooking projects which involve the issuance of carbon credits: **”What is a possible design for a digital multi-actor platform for the issuance of carbon credits?”**. Literature and the research commissioner suggest introducing real-time data collection in combination with an information system for the described problem as introduced in subsection 1.2.2. However, similar information systems have been suggested, and their architecture has been described (Woo et al., 2021). Even though there are

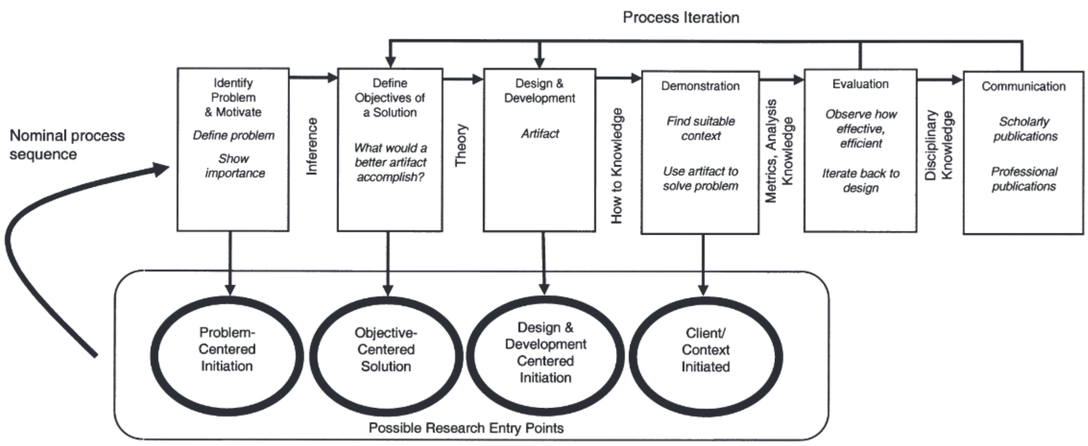

Figure 2.1: DSRM Process Model (Peffers et al., 2014, p. 10)

information systems designs and architectures of which certain building blocks can be used, no satisfactory solution has yet been approved for usage by the FCF. While possible architecture characteristics of technologies such as distributed ledger technology have been discussed, they still have to be analysed for suitability (N. Van der Geest, personal communication, March 14, 2023). The exclusive re-usage of information architecture building blocks is not expected to lead to the desired system capabilities. Therefore, some building blocks must be designed from scratch according to requirements. This research aims to fulfil all involved stakeholder needs to an acceptable level. The generation of an information architecture in an academic context can be considered the generation of an artefact (Hevner et al., 2004). Design science research methodologies are an ideal fit for the research question mentioned above (Peffers et al., 2014). A representation of the introduced cycle is displayed in Figure 2.1. However, design science research still exhibits several methodological flaws that must be addressed to improve the maturity of the artefacts produced from it. For instance, methodological support for problem formulation is remarkably lacking. Additionally, design science research does not offer detailed procedure models which can be reproduced and operationalised (Braun et al., 2015). The future purpose of this research, in addition to scientific contribution and the provision of a reference architecture for similar challenges, is also a seamless handover to platform developers. Considering the identified lack of operationalizability by Braun et al. (2015) and the introduced concept of a requirements-driven design science research, another design approach is introduced. A systems engineering life cycle process model and model-based systems engineering, which is an approach to systems engineering. Both are used in this research (Holt et al., 2015). The suggested requirements-driven approach by Braun et al. (2015) is nested within systems engineering (International Organization for Standardization, 2018) and therefore provides justification for the usage of a systems engineering approach in academic research. The match between the design science research methodology by Peffers et al. (2014) and a requirements-driven design approach as suggested by Braun et al. (2015) is visualized in Figure 2.2. Model-based systems engineering is an applied modelling approach to support system requirements, design, analysis, verification, and validation activities (Walden et al., 2015). Concepts used in model-based systems engineering will enable a seamless handover to developers for implementation, using standardised and non-ambiguous communication (Hirshorn et al., 2017). While the proposed design science research methodology by Peffers et al. (2014) matches well with systems engineering life cycle processes, the life cycle processes do not emphasise the evaluation and communication of design artefacts. Therefore, these steps of the research use the design science research processes as suggested by Peffers et al. (2014).

2.1. Research strategy

This section and the following explain the steps involved in deriving answers to the main and the sub-research questions shown in Figure 2.3. To answer the main research question, which is the design of an artefact, sub-research questions adhere to applicable steps of the proposed system life cycle processes as introduced by the International Council on Systems Engineering (INCOSE) and the underlying standard for system life cycle processes by the International Organization for Standardization (International Organization for Standardization, 2018) which is shown in Figure 2.4. The detailed description of activities given by the life cycle stages and the even more elaborate explanation of INCOSE are used for the execution of each applicable step. Walden et al. (2015) suggest limiting the usage of stages to the applicable amount depending on individual project context. Since the goal of this research is to provide a high-

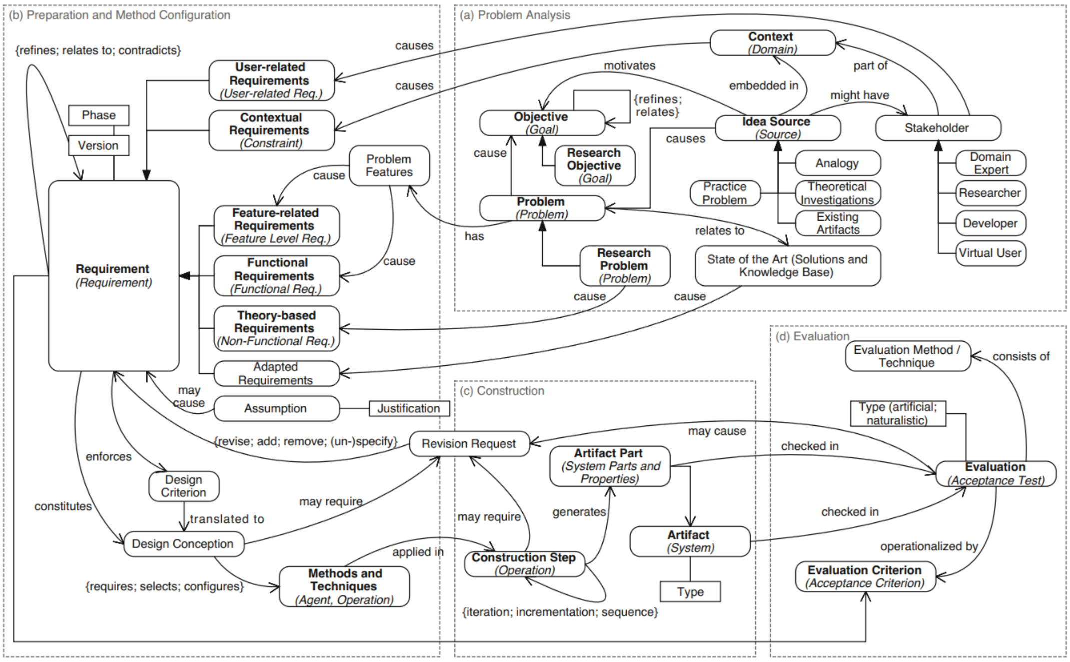

Figure 2.2: Ontology for requirements driven DSR (Braun et al., 2015, p. 9)

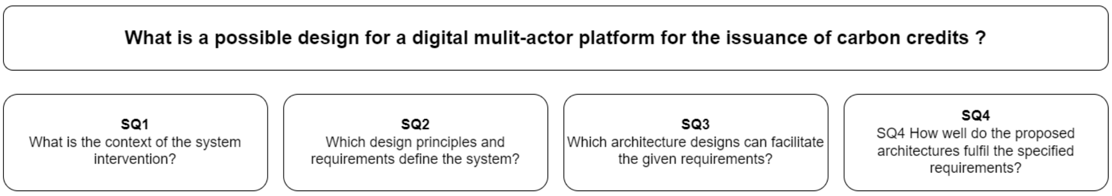

Figure 2.3: Main research and sub-research questions

level, conceptual system architecture and the subsequent design steps, the research covers only the *”Concept”* and *”Development”* stages of the life cycle model.

What is the context of the system intervention? This section provides reasoning for the first sub-research question and elaborates on the tasks necessary to answer it. The process of issuing carbon credits for projects in developing countries has been established for quite some time (Gill-Wiehl et al., 2023). However, as mentioned earlier, this is a tedious process that involves multiple stakeholders. To design an information architecture that facilitates improvements to the process, an inventory of stakeholders and their corresponding process steps has to be done. The resulting overview will serve as a baseline to analyse the process. As input for this step, FCF documents will be analysed to derive the process steps. Desk research will serve as a means to cross-verify the gathered information. This is a crucial step in the research process and corresponds to the generic life cycle stages *”Exploratory”* and *”concept”* (Walden et al., 2015). Namely, the definition of problem space. Considering that this step will lay the foundation for the research, it needs to be thoroughly executed. Lacking identification of process steps and system functionality will result in a failed system design, which must be avoided by all means (Hirshorn et al., 2017). Therefore, model-based systems engi-

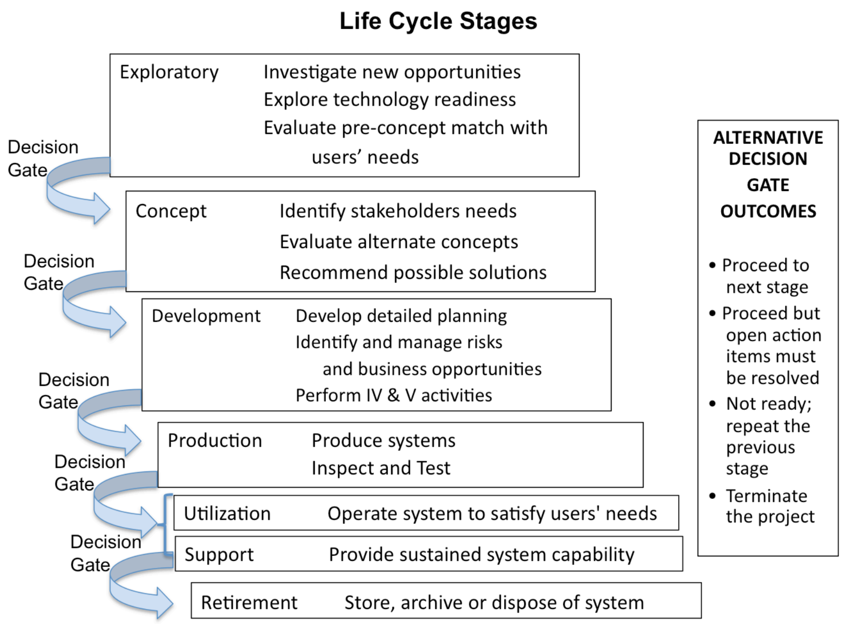

Figure 2.4: ISO15288:2023 Life Cycle Stages (Fairley & Forsberg, n.d.)

neering approaches such as a behaviour modelling of the current process will be conducted (Holt, 2021). Behaviour modeling refers to the functional analysis of a system and therefore visualizes the system's required functionality to achieve the desired outcome (Walden et al., 2015). In addition to a behavioural view of the system, the corresponding stakeholders for each of the steps will be identified and visualized in a system context diagram, which aids the establishment of the System of Interest(SOI) boundaries (International Organization for Standardization, 2018). All generated artefacts in that step will adhere to industry standards to enable the handover mentioned above to platform developers. As for all steps of the research, concepts of model-based systems engineering will be used. This will also ensure the traceability of design decisions throughout the process (Walden et al., 2015). The second step of the research will also adhere to the proposed generic life cycle stage (Walden et al., 2015). Defining the objectives of a solution requires capturing stakeholder needs. Objectives have to be derived from all stakeholder perspectives, and these perspectives can be considered "Stakeholder needs", which is a common term used in systems engineering and model-based systems engineering methodologies (Walden et al., 2015). It can not be expected that stakeholders are familiar with requirement engineering terminology and the formulation of requirements. However, non-ambiguous language in formulating requirements is necessary, and requirements should comply with a standard. Therefore, stakeholder needs are gathered and reformulated to adhere to the mentioned standards. This introduces the researcher as a determinant, to curb the consequences, requirements engineering techniques will be used (Walden et al., 2015). The identification of stakeholder needs is made by the conduction of interviews. The semi-structured interviews ensure all necessary points are discussed while leaving room to discover non-anticipated needs (Alshenqeeti, 2014).

Which design principles and requirements define the system? This section describes and reasons for the process of requirements elicitation. The previously captured stakeholder needs have to be translated into properly formulated requirements which will serve as input for the architecture design and later verification procedures (Walden et al., 2015). However, stakeholder needs are only one input for this step; the second fundamental input for this stage can be found in the second half of this section. Stakeholders are expected to give input regarding their expectations of the system. In the requirement elicitation phase, it is crucial that these expectations are questioned and their root cause is identified. Stakeholders often suggest solutions that need to be avoided by all means at this stage of system development (Holt, 2021). This requires the systems engineer to thoroughly analyze captured needs and ensure that formulated requirements are reviewed with the stakeholders for verification. Stakeholder needs in multi-actor systems incorporating multiple stakeholders are also expected to be non-harmonious. Contradicting needs are common, and a prioritization of formulated requirements is necessary. The generated power-interest grid will help to conduct the prioritization (Walden et al., 2015). The stakeholder needs will mainly be derived from interviews and internal and public documents of discovered stakeholders. Conducting interviews imposes the risk of a lack of decisive information due to the non-availability of interviewees or stakeholders opposing the system who refuse participation in design process steps. However, stakeholders opposing the system are not expected, and the lack of availability will be curbed by early planning of interview phases and substitutional measures such as desk research. The second input category for the elicitation of system requirements is design principles. In information systems, design principles relate to fundamental ideas and concepts that guide developing and designing effective and efficient information systems (Gregor et al., 2020). These principles govern decision-making and form the system's overall structure and functionality. Practitioners use design principles for applications in practice and researchers for knowledge capturing. For the documentation of design principles and requirements, model-based systems engineering approaches will be used, as will be for the whole system design, to ensure traceability and the previously mentioned handover to platform developers. An overview of model-based systems engineering methodologies and their application cases can be found in the publication by Di Maio et al. (2021).

Which architecture designs can facilitate the specified requirements? This section provides and overview of the third sub research question. The architecture and design process generates a system architecture and, depending on the use case, different variants. These alternative architectures are required to reflect stakeholder needs captured as requirements in the previous step (Walden et al., 2015). The system architecture enables the creation of a holistic solution incorporating design principles and requirements, ideally making them consistent. In design science, the research context is referred to as the generated artefact of this research (Peffers et al., 2014)(Walden et al., 2015). The creation of the architecture will be facilitated and visualized using model-based systems engineering modelling techniques. At least two architecture models will be assessed against system requirements. In addition to the architecture models, a list of imperative interfaces. Trade-offs, improvements and suggestions will be added to the models to lay the foundation for the following research step.

How well do the proposed architectures fulfil the specified requirements? This section highlights the importance of validation and the proposed steps for the execution of such. To ensure usability and a viable state-of-the-art architecture model, it is essential to go through a proper verification cycle (Holt, 2021). This process step provides objective evidence that a system fulfils its specified requirements (Walden et al., 2015). The verification of the architecture model will be done with the help of experts. Expertise from experts in different fields must be considered in this step. There are two aspects of the architecture that need to be validated. The first one is how well it fulfils the stakeholder needs. The second aspect focuses on the technical viability of the architecture. The verification tests if the proposed architecture meets the intended functionality. It is also expected to discover and highlight design flaws that need improvement before the platform is developed. The early detection of issues in the design reduces the likelihood of the system being reworked at a later stage (Walden et al., 2015). In addition, information systems architecture verification helps with the reflection and analysis of the effectivity of used design steps, which is also part of the artefact and then be improved by future researchers in similar use cases. However, it is also crucial for knowledge creation in the academic sector to verify the architecture model. It is of fundamental importance to achieve credibility that experts review the produced artefact. The discussed research flow is also shown in Figure A.1.

2.2. Combined approach and document structure

The previously introduced research methods, namely design science research by Peffers et al. (2014) and the systems engineering methodology proposed by Walden et al. (2015) strongly influenced the decomposition of the main research question into the four sub-research questions and therefore also the structure of this document. It's important to note that the steps of design science research and the chosen systems engineering approach do not perfectly align with each other in a one-to-one manner. However, combining these approaches enhances the research process by offering a comprehensive problem-solving strategy. An overview of how the corresponding design cycle steps and the sub-research questions relate to each other is provided in Figure 2.5. The research documentation follows the structure of a design cycle in accordance with answering the sub-research questions in sequence. The chapter 3 answers the sub-research question referring to the context in which the information system will operate. This means discovering the overall process of carbon credit issuance in clean cooking projects and the relevant stakeholders. The following chapter 4, uses the previous finding to derive requirements for the system. Contextual variables such as stakeholders and institutions impose requirements on the system, which are listed and analysed for their type for the subsequent design cycle steps. The overview of requirements answers the second sub-research question by listing the defined system requirements. The following chapter 5 utilises the captured requirements into a functional architecture, describing the overall desired behaviour of

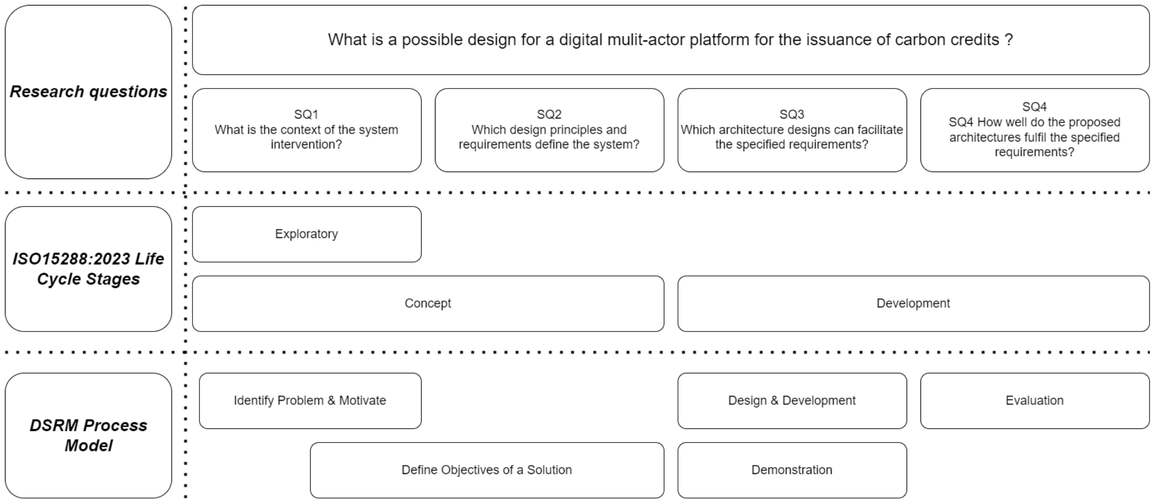

Figure 2.5: Mapping of design cycles and research questions

the information system by decomposing it into functions. The functional decomposition is then grouped into logical system elements to provide the system architecture mentioned in the third sub-research question. In addition, the logical system architecture is used to define possible technological solutions, finalising chapter 6. In the last step, in chapter 7, the functional architecture and proposed technologies are analysed for their suitability concerning the specified requirements. The overall document is finalised by chapter 8, which comprises a discussion and a conclusion.

3
Context analysis

This chapter presents a research study addressing the question: ”What are the key challenges and bottlenecks in the current process of issuing carbon credits in clean-cooking projects?” The research approach utilised in this study is a systems engineering approach, which begins with a comprehensive stakeholder analysis, followed by a process analysis and description, also referred to as mission analysis (Walden et al., 2015). This approach aims to identify the context of the socio-technical intervention of the SOI. To do so, an inventory of involved stakeholders is created, and the functions fulfilled by various stakeholders in the system are assigned to them. Identifying stakeholders and their corresponding functions enables the researcher to approach the relevant parties for interviews to derive requirements and further understand their involvement in the SOI. This aligns with the systems engineering approach by Walden et al. (2015). Therefore, this chapter’s outcome is a description of the system context, high-level functionality and the involved parties. It also describes the power dynamics within the SOI. A process model relating chapter to each other is shown in Figure 3.1.

The research draws information from two primary sources: observatory participation and desk research. Observatory participation, a qualitative data collection method commonly employed in social sciences, allows for an in-depth exploration of human experiences and behaviours within a specific context (Schubotz, 2019). The choice of observatory participation as a research approach was driven by the absence of precursor projects and limited academic literature on the specific topic of interest, which revolves around the ongoing execution of the sustainable finance project undertaken by the FCF. Observatory research was conducted by directly speaking to project developers of clean cooking projects, the head of finance and the director of the FairClimateFund. Information derived from attending meetings on relevant topics was also used to analyse the context.

The sustainable finance project, particularly its clean cooking initiative, is a small-scale pioneering endeavour. As such, its procedural aspects present a valuable opportunity for thorough investigation through the selected research approach. By delving into the organisational structure and processes involved, the study aims to shed light on the challenges and

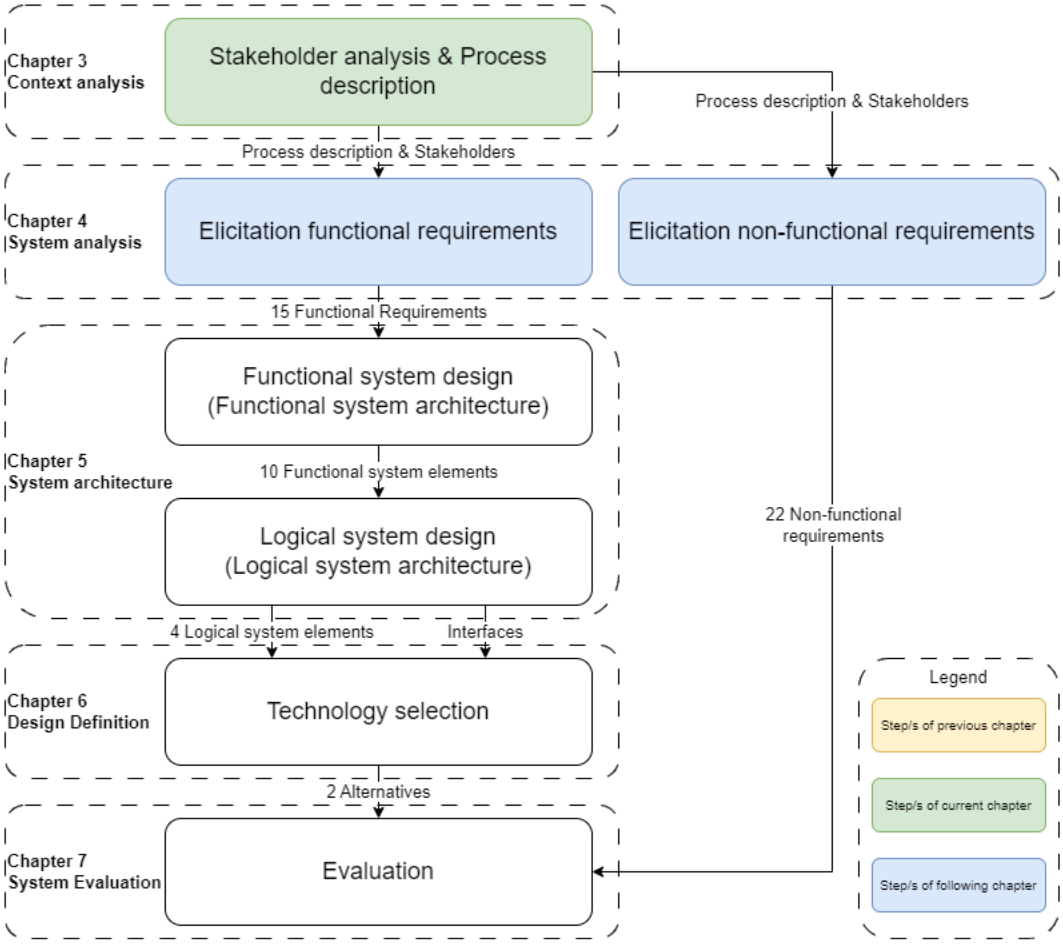

Figure 3.1: Process model

bottlenecks that arise during the issuance of carbon credits in the context of clean-cooking projects.

To ensure the accuracy and validity of the findings, this research section is subject to review by the FCF, the party responsible for developing the sustainable finance project. Their input and collaboration in the research process will further enhance the reliability of the study's outcomes.

3.1. Voluntary carbon credit market

The voluntary carbon credit market is a platform in the larger picture of carbon emissions reduction. In this industry, businesses and individuals take action to offset their carbon footprints by investing in projects that reduce greenhouse gas emissions (Kreibich & Hermwille, 2021). Instead of regulatory-driven processes, voluntary carbon credits provide a more flexible and voluntary approach, allowing companies to link their sustainability efforts with environmental goals beyond legal duties (Bayon et al., 2012). This market helps to develop a culture of environmental stewardship across businesses and regions. The following stakeholder analysis focuses on one specific case within the voluntary carbon credit market. It can serve as an example case for developing digital, IoT-driven platforms within sustainable finance projects.

3.2. The FairClimateFund Case

The FairClimateFund's initiative to establish a pilot program in Rwanda, in which clean cookstoves will be distributed. The pilot focuses on real-time monitoring of these clean cookstoves and implementing an information system for calculating and issuing carbon credits. The case serves as an illuminating case study within the context of this research. Employing a case study approach provides the author with a valuable opportunity to conduct a comprehensive design cycle, offering a practical blueprint that aids practitioners and researchers in comprehending the intricacies of this innovative endeavour.

3.3. Stakeholder Analysis

This stakeholder analysis identifies roles in the system and their corresponding actors (Varvasovszky & Brugha, 2000). To answer the first sub-question, which entails the analysis of the carbon credit issuance process presently proposed by the FCF, it is required to understand the relationships between actors and the corresponding processes in the system. As a first step, such an analysis incorporates the creation of a stakeholder inventory (Walden et al., 2015). The to-be-designed artefact is referred to as SOI, which is defined as the system whose life cycle is under consideration (International Organization for Standardization, 2018). The SOI is a socio-technical system comprised of various system elements and their interactions between them. The approach to creating a clear overview is to allocate system functions and, in this case, process steps of carbon credit issuance to the executing party, making the parties a system element themselves. System elements are the interacting components, usually technical subsystems (Walden et al., 2015). The information on the current carbon credit issuance process used by the FCF will be broken down into logically sequenced steps. These process steps are then mapped on the identified stakeholders to create an overview of the functioning of the SOI, including the executing system element.

3.3.1. Stakeholder overview

This section introduces the stakeholders of the SOI and describes their role in the current carbon credit issuance process proposed by the FCF. The stakeholder overview contains the general description, the case-specific description, the business objective or mission, and the role in the system.

3.3.2. Project developer

General role description: The stakeholder project developer in this research refers to the party initiating an intervention within a socio-technical system.
Case description: Through funding locally-driven climate action initiatives in developing countries, the Fair Climate Fund aims to combat climate change and improve environmental justice. The organisation recognises that marginalised communities experience the effects of climate change more severely than other groups do and that they have few resources to cope with and mitigate these effects. Governments, for-profit companies, and private citizens committed to climate justice contribute money to the Fair Climate Fund, which then accumulates these

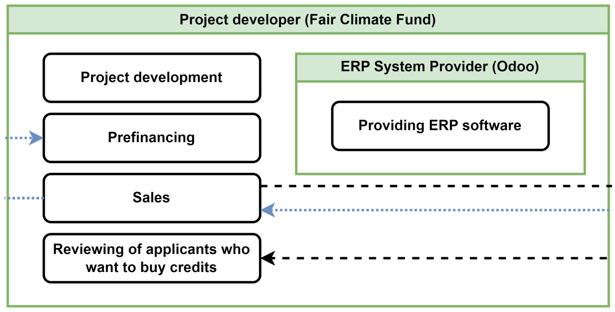

Figure 3.2: Project developer and corresponding functions

funds to support its operations. These funds are then used to support initiatives created and carried out by local groups, ensuring their active involvement and ownership (FairClimate-Fund, n.d.-b).
Business objective: Their objective is to collaborate with their partners to offer cleaner cooking options to 500,000 people and to plant 500,000 trees in order to offset a million tonnes of CO2 before the year 2025 (FairClimateFund, n.d.-c).
Role: The FCF, is the initiating party of clean cooking projects. Promising communities in developing countries are scoped, and the required project design is conducted by the FCF. The FCF also organises the pre-financing of projects and the sales of the issued carbon credits. During project execution, the project developer also monitors the project. Depending on the purchasing party, the FCF reviews the party and decides if the transaction is approved. An overview of the project developers' functions in the system is displayed in Figure 3.2.

Standardization body

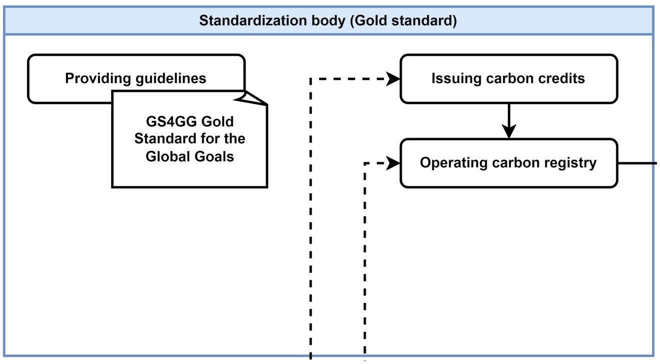

Figure 3.3: Standardisation body and corresponding functions

General role description: The standardisation body is the party that issues standards in sustainable finance projects. These standards aim to enable the comparability and trustworthiness of sustainable finance projects (Woo et al., 2021).
Case description: The Gold Standard Certification Agency certifies worldwide projects exhibiting social and environmental sustainability. The organisation establishes requirements and standards for several industries, including water management, forestry, agriculture, and renewable energy. An assessment procedure determines if projects seeking Gold Standard

certification positively affect community participation, sustainable development, and climate change mitigation. The certification shows that a project complies with the requirements for emission reductions, environmentally friendly methods, and beneficial social effects. It guarantees stakeholders that the project complies with their requirements, has undergone independent verification, and is advancing global sustainability goals (GoldStandard, n.d.)(Gill-Wiehl et al., 2023).
Business objective: Through establishing standards and confirming the impacts of projects worldwide, Gold Standard aims to hasten the achievement of the Sustainable Development Goals and the Paris Agreement. Three strategic pillars—environmental markets, corporate sustainability, and climate finance—are the focus of their strategy (GoldStandard, n.d.).
Role: Gold Standard has the role of creating standards and guidelines which have to be followed to register carbon credits under their Gold Standard certification label, which is the required label by the FCF (FairClimateFund, n.d.-a). The gold standard also provides the most accurate measurement reporting and verification (MRV) method according to academia and, therefore, is a suitable source for standards (Gill-Wiehl et al., 2023). The Gold Standard also operates the currently used carbon registry, which can be referred to as a storage for carbon credits. A summary of the functionalities in the SOI, see Figure 3.3.

Verification body

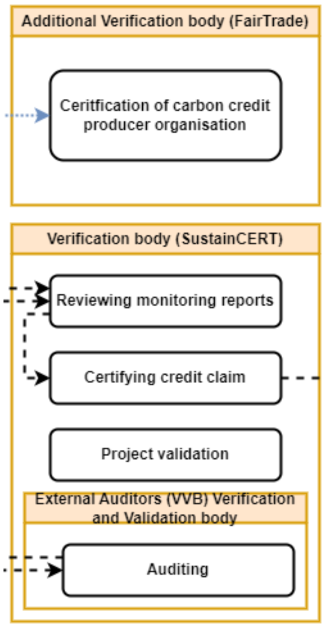

Figure 3.4: Verification bodies and corresponding functions

General description: Verification bodies verify that sustainable finance projects meet specific criteria, such as the standards created by standardisation bodies. The verification bodies audit projects and certify them in case of successful audits.
Case description: In 2018, Gold Standard established SustainCert, a certification organisation focusing on sustainability and ethical sourcing. SustainCert provides certifications that guarantee conformity to certain environmental, social, and economic norms, emphasising the

agriculture and forestry industries. Their certificates offer independent verification and certification for businesses that exhibit sustainable practices, moral sourcing, and accountable supply chain management. The assessments offered by SustainCert encompass a range of standards, including carbon footprint reduction, fair labour practices, and biodiversity preservation (SustainCert, n.d.).
Business objective: SustainCERT's business objective is to create and establish digital verification solutions to improve MRV processes and enhance their credibility (SustainCert, n.d.).
Role: SustainCERT's task is to use assessment procedures created by Gold Standard to assess the project and certify the project and the issued credits in case of a successful assessment. One of the core functions is calculating the emission reduction and providing the information for the issued carbon credits. An overview of verification bodies functions is shown in Figure 3.4.

Cookstove provider

General description: The cookstove provider provides the cookstove, the physical means enabling carbon emission reduction. The cookstove providers develop and produce the cookstove.
Case description: Mimi Moto is a Netherlands-based company producing the TIER-4 wood gasification (MimiMoto, n.d.) certified cookstove (Mimi Moto pellet stove). Their approach to reducing indoor air pollution and carbon emissions through clean cooking works by combining a more efficient cookstove than traditional means of cooking and locally available biomass as fuel. The intended fuel for use is pellets ideally made from locally produced sawdust.
Business objective: Mimi Moto aims to work with local entrepreneurs to scale their businesses. In addition to the sales of the cookstoves, they also provide lessons learned from past projects and support to entrepreneurs looking to start a business using their cookstoves (MimiMoto, n.d.).
Role: In the SOI, Mimi Moto sells the project cookstoves to the fuel provider, which the fuel provider then distributes. The fulfilled functions by the cook stove provider are presented in Figure 3.5.

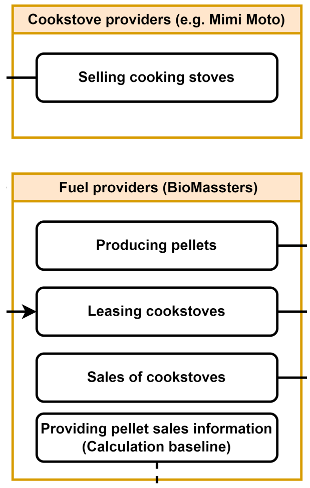

Figure 3.5: Cookstove and fuel provider and their corresponding functions

Fuel provider

General description: The fuel providers do provide alternative cooking solutions with fuel. The alternatives that substitute traditional cooking means can vary (Champion & Grieshop, 2019)(Freeman & Zerriffi, 2014).
Case description: In the case given by the FCF, the chosen fuel are pellets. These pellets are produced in factories close to the cookstove users by BioMassters. BioMassters' secondary function is the purchase and provision of 1400 Mimi Moto pellet stoves to the project subject,

namely the households in Rwanda.
Business objective: BioMasster's business objective is to replace charcoal for cooking by producing wood pellets which can be used instead. The pellets are made from waste, so no biomass is processed solely for production. BioMassters has a "pay as you go" purchase model. In simple terms, this means that they hand out cookstoves for free with the condition that fuel is purchased from them, which in the long run reimburses them for providing the cookstove (BioMassters, n.d.).
Role: BioMassters is the fuel provider for cookstoves. They also provide information on sold pellets, enabling the triangulation of data streams regarding emission reduction. BioMassters also distributes the cookstoves to households via a leasing model or purchases. The fulfilled functions by the fuel provider are displayed in Figure 3.5.

Funding parties

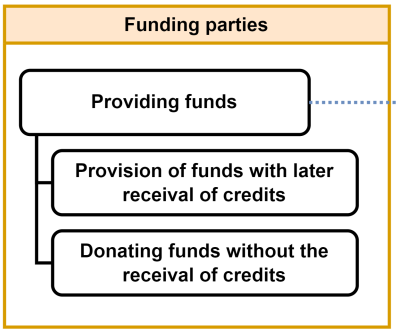

Figure 3.6: Funding parties and their corresponding functions

General description: Funding parties provide financial resources for sustainable finance projects. These parties can be classified into two groups. The first group provides funding without any return. The other group provides funding for projects with the condition that they will receive carbon credits once the project runs.
Case description: N/A since there is no defined funding party for the project yet.
Business objective: N/A since there is no defined funding party for the project yet.
Role: The role of a funding party is to provide financial resources for the project to be set up; their functions can be found in Figure 3.6.

Purchasing parties

General description: Purchasing parties are stakeholders who purchase carbon credits. They split into three different sub-parties. Individual purchasing parties are persons who want to offset their carbon footprint. Private purchasing parties are companies that are offsetting emissions resulting from business operations. Reselling parties are companies that purchase carbon credits to resell the carbon credits to third parties.
Case description: N/A since there is no defined purchasing party for the project yet.
Business objective: N/A since there is no defined purchasing party for the project yet.
Role: Purchasing parties in the SOI purchase the issued carbon credits for various purposes. The role of purchasing parties varies depending on the credit amount purchased and what

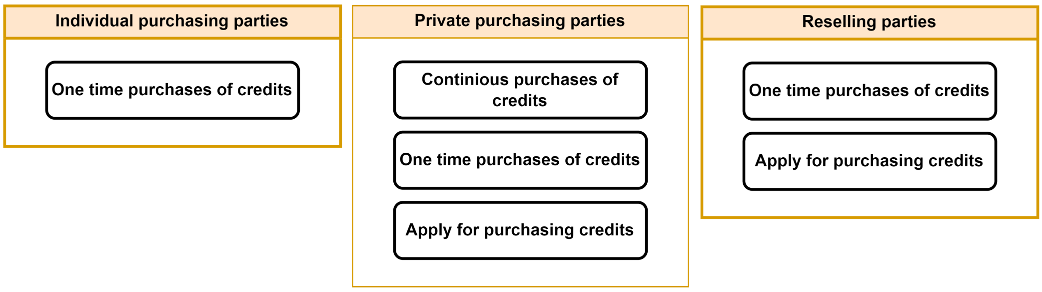

Figure 3.7: Purchasing parties and their corresponding functions

kind of party makes a purchase. Some large quantity purchases of carbon credits require an application before the purchase of carbon credits is accepted by the FairClimateFund. The functions are visualised in Figure 3.7.

Project subject

General description: The project subject in sustainable finance projects is the actor in the SOI whose behaviour change in combination with the means enabled through funding results in the reduction of GHG emissions.
Case description: In the FCF case, households in Rwanda are the project subject. The households in Kigali purchase the cookstoves and switch from burning wood or charcoal to the gasification of pellets with the Mimi Moto pellet cookstove. Reducing the GHG emissions form the baseline for issuing carbon credits (Freeman & Zerriffi, 2014).
Business objective: The business objective of the household can be described as improving their financial burdens regarding fuel for cooking. The Mimi Moto pellet stove's usage is likely due to fuel cost reductions (Jagger & Das, 2018)(BioMassters, n.d.).
Role: The households use the cookstoves and purchase the pellets. The behaviour change of households, which means a change from traditional cooking ways to the usage of the Mimi Moto pellet stove, reduces carbon emitted within these households. For certification purposes, the households have to fill out surveys. Households are also recipients of income from carbon credits. A functional overview of the project subject is shown in Figure 3.8.

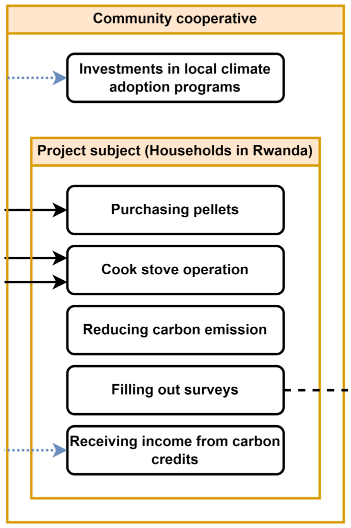

Figure 3.8: Community cooperative, project subject and their corresponding functions

Community cooperatives

General description: Community cooperatives are created through cooperation between all project subjects. Certain larger investments can only be carried out by a collaboration of individuals. Therefore, community cooperatives are created, and the benefits -resulting from investments are shared with the whole community.
Case description: For this specific project, the community cooperative comprises the 1400 households that will receive a Mimi Moto pellet cookstove. Regarding FairTrade-certified car-

bon credits, 1€ per issued credit will go to the community cooperative, not taking away from the household reward but serving as an addition. The cooperative can invest the accumulated amount in any local climate adoption programs that fit the requirements FairTrade imposes.
Business objective: The goal of the community cooperatives is to decide and execute local climate adoption programs of such a large scale that local individuals cannot carry them out. An example of such a project is a small solar farm that the whole community can use.
Role: The community cooperative receives 1€ per issued credit, which the cooperative reinvests in local climate adoption programs. The community cooperatives function is shown in Figure 3.8.

Institutions

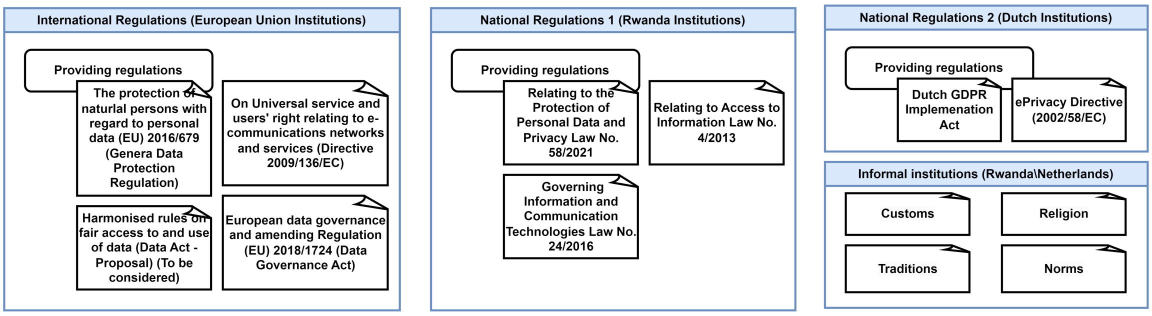

Figure 3.9: International, national and informal institutions

General description: Institutions impose standards, regulations and policies that influence the system through all its life cycle stages. More than one institution must be considered within a socio-technical system such as the SOI, which spans various countries and continents. Regulations and policies, such as the ones on the protection of data, differ, and the institutional context of all countries of operation has to be analysed. In addition to the national and international institutions, there are informal institutions such as customs, traditions, religion and norms. These informal institutions are context-dependent and change within every community (Helmke & Levitsky, 2004).
Case description: In the clean cooking project of the FCF there is the European union, as international regulator. Since the country the FCF operates from, the Netherlands, is located within the European Union, various regulations of the European Union influence the system. The Netherlands also have a set of regulations which have to be considered. The project will take place in Rwanda, making it the third institutional stakeholder imposing regulations. An overview of the case-specific stakeholders and the regulatory documents they provide can be found in Figure 3.9.
Business objective: Institutions concerning information systems set regulations to protect citizens' rights. By regulating the collection, use, storage, and sharing of personal information, the main goal is to preserve people's privacy. The regulations demand specific consent for all data processing operations to prevent unauthorised access to or publication of personal data (Hsu et al., 2012).
Role: All institutions provide regulations, policies and guidelines for all life-cycle stages of the

SOI. The functionality provided by institutions is the provision of regulations and policies. The overview of the context-specific documents is displayed in Figure 3.9.

External Auditors

General description: External auditors are parties tasked with auditing procedures by the verification body. They are independent organisations which are sub-contracted by the verification body. External auditors audit projects after the project launch and verify that the project is executed as the project developer claims.
Case description: N/A since no external auditor is defined for the project yet.
Business objective: N/A since no external auditor is defined for the project yet.
Role: Their role in the SOI is to collect data on the launched project through the execution and review of surveys. The surveys are either handed out to households or filled in by external auditors while visiting the households.

ERP System provider

General description: ERP systems or internal systems, in general, can be used by various stakeholders. Typically, these systems are used in companies and aim to combine business-relevant data streams within one information system.
Case description: Odoo, the company, is the ERP systems provider for the project developer. The FCF(project developer) connects various internal data streams through the ERP system. Therefore, the used information system has to be considered in the SOI.
Business objective: Odoo aims to provide easy-to-use business applications to its users. The open-source community of Odoo helps customers with specific needs.
Role: The provision of the ERP system of the project developer.

3.4. Process description

The basic idea of carbon credit issuance in sustainable finance projects has been discussed in the previous chapter. This section explains the process of carbon credit issuance in sustainable finance projects using clean cookstoves. The information for this section has been derived through the previously mentioned observatory research and conducted interviews. It is worth mentioning that in the FCF case, the specific cookstove technology is the pellet gasification stove of Mimi Moto.

The project developer, the FCF, initiates the project by starting the project development. The FCF researches possible areas of employment for the project. The details of this process are not part of this research. A budget approximation is made, and possible stakeholders are contacted in addition to deciding on other project points. The project is described and documented in a project plan document. The project plan document is sent to the verification body for project certification. The verification body requires a project plan document for the later issuance of carbon credits and overall project certification (Freeman & Zerriffi, 2014). According to the budget plan and the project plan document, stakeholders are contacted to acquire funds for the pre-financing of the project. The initial investment in sustainable finance projects mainly serves the purpose of financing the cookstoves and the access to pellets (Jagger &

Das, 2018).

The fuel provider distributes the purchased cookstoves. As mentioned, the fuel provider, BioMasster, who provides the pellets by establishing a local pellet production facility, distributes the cookstoves to households in the area. The cookstoves are distributed to households that agree to a leasing model of the cookstoves in the FCF case. In simple terms, that means that the families agree to obtain the fuel exclusively from BioMasster. Simultaneously, pellet production is established. Pellets are produced from local organic waste products, mainly sawdust from furniture production (Jagger & Das, 2018). The households operate the cookstove with the pellets purchased from the fuel provider.

The information on these purchases is recorded by the fuel provider and forwarded to the verification body. The cookstove operation with the pellets improves indoor air quality in the case of an indoor kitchen. It also reduces the emitted GHG emission. This results from the behaviour change of households. Instead of the traditionally used burning of wood and coal, the gasification of pellets results in the two above-mentioned major factors (Jagger & Das, 2018). In complex socio-technical systems, behaviour changes also affect other systems. The change to pellets also reduces the pressure on local forests, often cut down to produce firewood (Mutshinyalo & Siebert, 2010). In return, that positively affects local wildlife and biodiversity (Mutshinyalo & Siebert, 2010). It becomes clear that the behaviour shift of households is the essential function within the SOI intervention. Therefore, the SOI intervention requires thorough analysis and safeguarding of that specific function. The households report the usage of cookstoves and fuel to the verification body through surveys.

Households are also visited for audits by verification bodies, either through the organisation themselves or external auditors. The verification body, which accumulates data from the fuel provider and the surveys filled out by households, audits the information according to the standards of the standardisation body. These standards encompass formulas for calculating GHG emissions. When the audits and calculations are completed, the verification body verifies the credit claim. The credit claim verification is then forwarded to the standardisation body, which is the Gold Standard in the FCF case. Also, the carbon credit registry operator the FCF uses in the case. The Gold Standard issues the carbon credits and keeps them in their registry until the credits are sold. The FCF has access to this registry and requests that they be deleted when sold to the purchasing entities. There are different purchasing parties, which determine if the purchasing party has to apply for the purchase or does not have to. In addition, this is also determined by the amount of credits. More significant amounts of credits in one purchase are negotiated and involve an internal decision-making process if the transaction is confirmed. Purchases can be either a single event or reoccurring events over a set period. The income from the sold credits is then used to pay off the initial funding and cover project development and overhead costs. The income left after the subtraction of these costs is then returned to the households, who are also ”rewarded” for their behaviour change through financial means. An additional 1€ per credit is also given to community cooperatives in the case of a credit certified by FairTrade. The system context diagram in Appendix B shows a complete overview of stakeholders and their corresponding functions.

3.4.1. Activity diagram

An additional view of the process in the form of an activity diagram is drawn to understand the sequential order of functions and how they relate to each other. Institutional stakeholders are not considered in the activity diagram because they unidirectional provide regulations that do not fall into the traditional definition of fulfilling a function in the system by Walden et al. (2015). The entire activity diagram is shown in Appendix B. Figure 3.10 displays the stakeholders responsible for the majority of functions in the system. Out of 23 system functions, 13, more than half, are assigned to 3 out of 8 stakeholders. It, therefore, becomes quite clear that the project developer, households and verification body enable the main functionality of the system. It is worth highlighting that without the other functions, a successful process of carbon credit issuance in clean cooking projects is impossible.
Nevertheless, it emphasises an uneven distribution of stakeholder functionality in the SOI. In addition to executing most functions within the system, the three stakeholders presented in Figure 3.10 also have the most interactions with other stakeholders, as visible in the complete activity diagram in Appendix B. Past and current experiences by the project developer have shown waiting times for the certification of credit claims of the verification body of up to two years. The understanding of the importance of stakeholders in the fulfilment of system functions, together with the findings from the next section, help to give input for involvement in system design in the latter chapters.

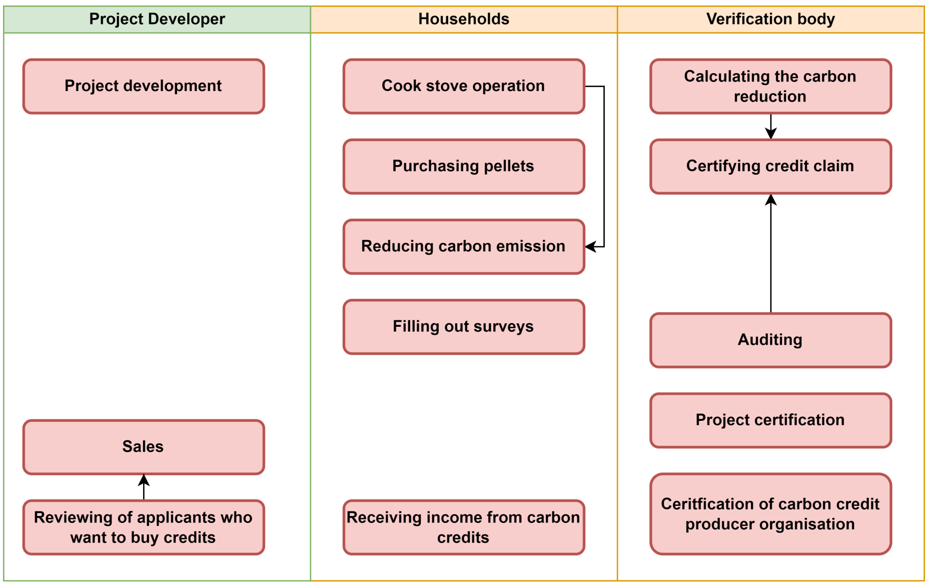

Figure 3.10: Stakeholders with the majority of system functions

3.5. Stakeholder Positioning

The stakeholder mapping and the process description in the previous sections lay the foundation for describing the stakeholder's positioning within the SOI. Within socio-technical systems, in which the coordination of multiple actors is required to achieve a common goal, it is crucial to understand the interest in participating in the system and how powerful the stakeholders are compared to each other (Ackermann & Eden, 2011). A power interest grid is developed to visualise the dimensions of interest and power. In Figure 3.11, the first dimension, interest, corresponds to the x-axis. The second dimension, power, corresponds to the y-axis. The grid is developed according to the actor classification approach by Bryson (2004) and the strategies and recommendations for the clustering of stakeholders by Ackermann and Eden (2011). Ackermann and Eden (2011) suggest grouping stakeholders into four categories. The following section uses the suggested approach and categorises the SOI stakeholders into four clusters, high-interest low-power (Subjects), hight-interest high-power (Players), low-interest low-power (Crowd), and low-interest high-power (Context Setters). The clustering of stakeholders according to Ackermann and Eden (2011) is necessary since the systems engineering approach by Walden et al. (2015) does not provide a structured approach for determining the most influential stakeholders. Walden et al. (2015) refer to stakeholders as all who can influence or be influenced by the system. For stakeholder consultation efforts and actor involvement, it is crucial to understand if actors influence the system and to what extent. As the term power is mentioned above, in the context of stakeholder determination by Walden et al. (2015), it refers to the extent to which stakeholders can influence the system. In addition to the power of stakeholders, the willingness to participate in the SOI intervention plays an important role. This research defines "interest" as the willingness to actively engage in the SOI intervention.

Simply put, that means a bidirectional communication effort between the party and other parties during at least one system life-cycle phase. The outcome of the clustering of stakeholders indicates the importance of needs consideration of these. This enables the classification of requirements to answer the second sub-research question. The requirements, which are reformulated stakeholder needs, are linked to the stakeholder and will have to be considered in the case of influential stakeholders but can be neglected or negotiated in the case of less powerful ones (Ackermann & Eden, 2011). The power interest grid is shown in Figure 3.11. For this research, no requirements were neglected or determined as having to be negotiated. However, the insight generated by the understanding that some stakeholders are more powerful than others is valuable for the project developer. Project developers are enabled to derive a plan for stakeholder consultation to achieve successful implementation of the system. The information derived for the positioning of stakeholders follows the basic brainstorming approach suggested by Bryson (2004).

3.5.1. Subjects

High-interest low-power stakeholders, who are clustered as subjects, are highly interested in participating in the SOI intervention. However, they do not hold much power to influence the system and are rather influenced by it. In the SOI, the fuel provider and the cookstove provider can be considered subjects. The fuel provider is highly interested in participation because their sole business model requires the sales of pellets to households. Therefore, it can be expected that the fuel provider is interested in participating to sustain its existence. The lack of power of fuel providers is because households can easily substitute the pellets using

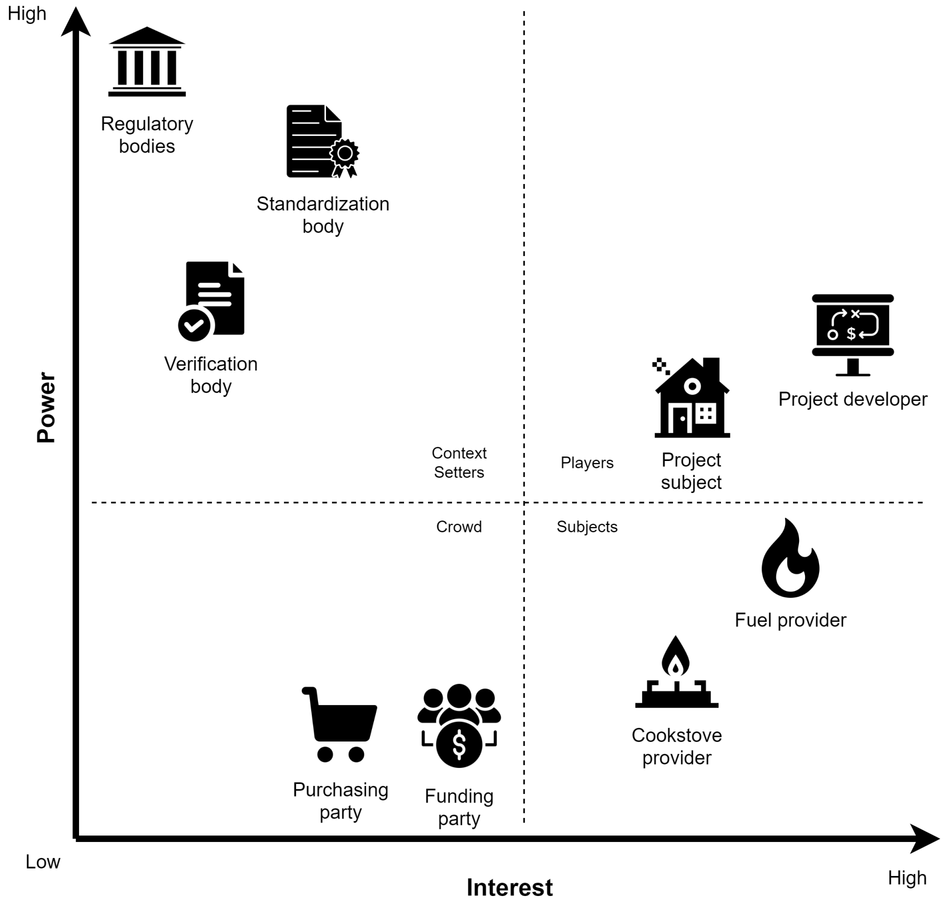

Figure 3.11: Power interest grid

other fuels or switch back to the traditionally used cooking fuel, rendering the fuel provider obsolete.
The cookstove provider is driven by similar motivation to participate in the system. Their business model relies on the sales of cookstoves, and involvement in the project from their side facilitates their company's growth. However, various cook stove providers offer many different cook stove models (Champion & Grieshop, 2019). The ability to switch to a different cook stove provider leaves them with little power in the System of interest (SOI).
It is suggested by Ackermann and Eden (2011) that subjects are loosely involved in the SOI design process, which means that requirements are imposed on them in a unidirectional way. Even though these parties do not hold much power and can relatively easily be substituted, a consultation is required. The exchange of these parties is expected to only result in minor changes of their requirements on the SOI.

3.5.2. Players

High-interest high-power stakeholders who fall into that category can be considered key actors in the SOI. This category fits two of the identified stakeholders. One of them, the project developer, is only considered in the grid to highlight its power in contrast to other stakeholders. The most important finding is that there are more powerful stakeholders than the project

developer. Therefore, the interest in participation is the highest amongst all players and is not further explained here.
The project subject is the other key actor in the SOI. The interest in participation in the system is motivated by several factors. Indoor air quality improvement, which encompasses health benefits for households, is understood to be the main one. In addition, switching to pellets as cooking fuel leads to a cost reduction. This means that the household income is less burdened by fuel purchases. Project subjects are considered influential players. The decision to not participate in the SOI at any given time after the project starts would render all efforts in that specific project useless. However, since households are scoped and approached ahead of the project's start, the risk of sudden non-participation is low. Nevertheless, households are vital actors, and their functions are critical to the SOI and, therefore, rather powerful.
Ackermann and Eden (2011) suggest closely involving stakeholders classified as players. This means actively communicating and thoroughly considering their needs and concerns to ensure the functionality of the SOI after the intervention.

3.5.3. Crowd

Low-interest low-power stakeholders, such as purchasing and funding parties, are to be considered but rarely involved in the SOI intervention design phase. Purchasing and funding parties are not yet defined in the FCF case and also change during the project. Funding might be sourced from one or multiple parties, and the overall amount of credits can be sold to one but most likely to multiple purchasing parties. Since both parties are easily interchangeable, they hold little to no power in the SOI. Their interest in active participation is also determined to be low. The lack of interest in active participation was also confirmed by the interview conducted with a purchasing party.
Stakeholders with low interest and power can still hold valuable information regarding the SOI. They, therefore, should be passively informed regarding the SOI (Ackermann & Eden, 2011). Requirements given by these stakeholders are not assigned a high weight in the SOI intervention design phase.

3.5.4. Context Setters

Low-interest high-power stakeholders, are described by Ackermann and Eden (2011) as actors who set the context of the SOI intervention. This group entails regulatory bodies, standardisation bodies and verification bodies. The group comprises the most powerful actors in the SOI. These stakeholders mostly require the intervention to comply with their regulations, standards and procedures.
Regulatory bodies, such as the international and national institutions of countries of intervention deployment, impose non-negotiable requirements. Non-negotiable refers to the unidirectional involvement of these stakeholders, which means that the system does not influence them but does influence them. This behaviour causes a shallow interest in participation. Regulatory bodies are the most influential actors in the system.
Standardisation bodies are similar to regulatory bodies. However, they differ since research

has shown that these stakeholders consider feedback from sustainable finance projects to adapt and improve their standards when necessary (Kreibich & Hermwille, 2021). Since standardisation bodies specifically develop standards for clean cooking projects, their interest in the field is higher than that of regulatory bodies. Since standardisation bodies only consider aggregated feedback from various projects but require compliance with their standards for project certification, they are the second most powerful actor with a relatively low interest.
Verification bodies are the last stakeholder in the low-interest, high-power group. These bodies make use of the standards established by standardisation bodies. The procedures they execute are processes the intervention must comply with. The verification bodies can be described as the standardisation bodies' executive arm. Verification bodies can be switched. However, there are few acceptable substitutes, and they must be certified by the standardisation bodies, making them a powerful actor.
Context setter's needs can be considered mandatory requirements on the SOI intervention and must be considered without compromise.

3.6. Key Findings

This chapter presents a comprehensive analysis of the SOI within the context of clean-cooking projects, aiming to address the primary sub-research question: "What is the context of the system intervention?" A system context diagram is introduced to answer this question, highlighting the involved stakeholders and their respective functions in the system. Additionally, the power-interest grid is employed to gain insights into stakeholder dynamics.
The combination of these approaches reveals that most functions within the SOI are carried out by three stakeholders, who also wield significant power in the system. While the unequal distribution of functions among stakeholders is not inherently problematic, empirical evidence from previous projects, such as a conducted pilot project with clean cookstoves in India, by the FairClimateFund demonstrates that the verification body, one of the three major stakeholders handling most functions, acts as a bottleneck within the system. The registration of credits and therefore enabling the FCF the sales of credits took up to two years from the point of application for registration. Moreover, it is noteworthy that verification bodies play a critical role as context setters in the system.
Furthermore, the analysis highlights the presence of various institutional stakeholders in the SOI, underscoring the importance of diligent compliance efforts in the design of interventions for the SOI.
In conclusion, these key findings shed light on the critical aspects and complexities within the SOI and provide valuable insights for the SOI intervention.

4 System Analysis

This chapter addresses the second sub-research question: "Which design principles and requirements define the system?". The significance of system requirements cannot be underestimated, as they lay the foundation for crucial aspects such as system architecture, design, integration, and verification, as highlighted by Walden et al. (2015). This study aims to develop a viable, stakeholder-accepted SOI intervention, making it vital to comprehensively capture stakeholder needs before embarking on the system architecture development. A critical aspect of eliciting system requirements is providing a minimal yet comprehensive set of high-level requirements input for the systems architecture design and subsequent verification processes. Each stakeholder contributes to the project with their expectations and limitations, making it essential to consider and capture their perspectives. The carbon credit issuance system within sustainable finance projects is a socio-technical system heavily reliant on the interactions between diverse stakeholders. Hence, it becomes fundamentally important to incorporate all perspectives into the requirement elicitation process. To achieve this, an analysis of each stakeholder's viewpoint is conducted, alongside an effective capturing of their needs. The researcher utilises a combination of desk research and interviews to extract and understand these stakeholder needs. In the subsequent step, these requirements suggest that features and limitations are analysed, aggregated and reformulated where necessary. Such reformulation becomes indispensable when stakeholders present requirements that may not be solution-free (International Organization for Standardization, 2018). Reformulation also tackles the issue of repetitive requirements given by stakeholders; repetitive or differently phrased requirements with the same meaning are aggregated. This system design stage aims to avoid imposing solutions prematurely and refrain from limiting the solution space. Therefore, the researcher endeavours to rephrase and investigate the root problems behind the suggestions provided by stakeholders (Holt et al., 2015). The reformulation of requirements in this research takes place after the conduction of interviews. Stakeholder needs captured during these interviews are directly rephrased into system requirements by the researcher. This approach ensures that the system requirements accurately reflect all stakeholders' core needs

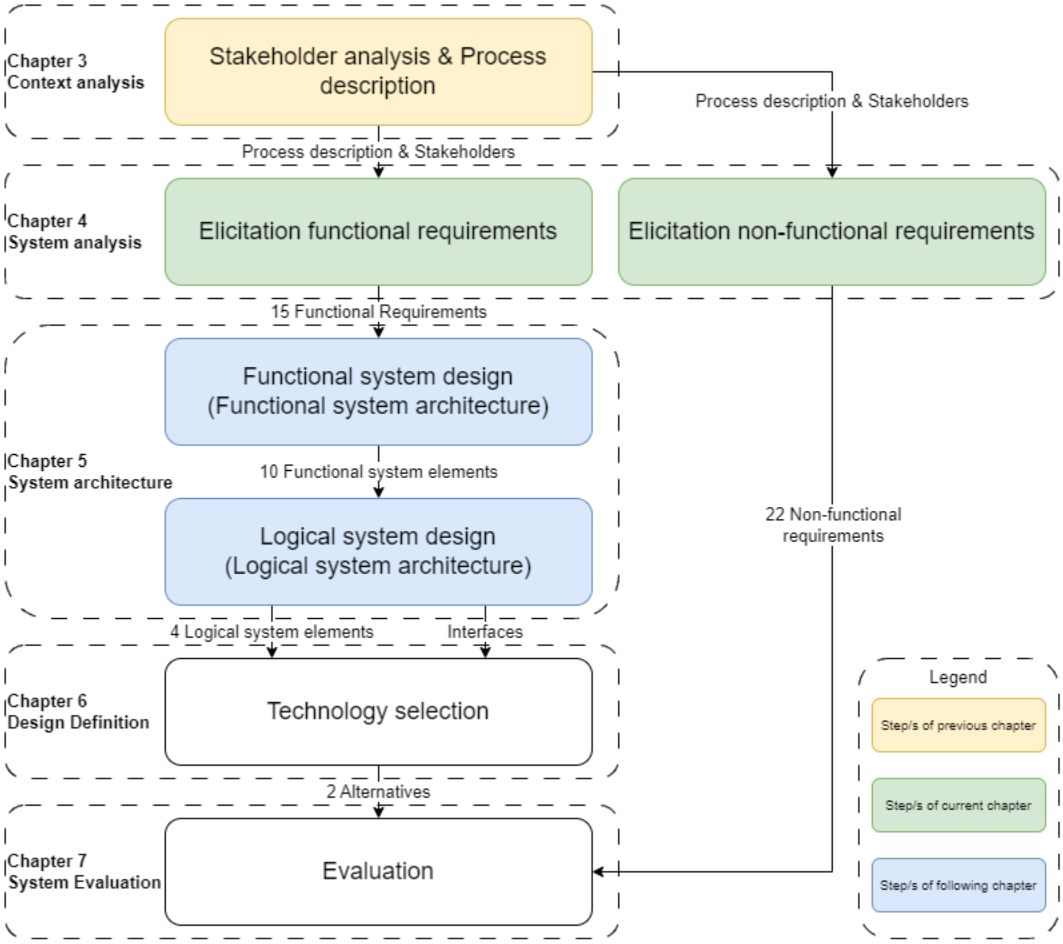

Figure 4.1: Process model

and aspirations, fostering a holistic system architecture design process. The research can explore various possibilities by staying solution-agnostic early and arrive at an innovative and effective SOI intervention. As the subsequent chapters unfold, the rich tapestry of stakeholder perspectives and requirements will be woven together to shape the future of sustainable finance projects and their vital role in addressing environmental challenges. An inventory of requirements is then used to derive a systems requirements classification. The classification is then analysed for its relationships and conflicting requirements.

4.1. System boundaries

As defined by Walden et al. (2015), the SOI is a system of systems. System of systems refers to inter-operational sub-systems of an overarching system. The sub-systems interact with each other to achieve a specific goal. In the FCF case, the system to improve carbon reduction and other factors can be seen as such a system of systems. While the cook stove, one of the systems, is also one of the systems enabling the reduction of carbon emissions. However, it cannot achieve the goal by itself. A system to provide fuel is required to do so as well. It is essential to understand the concept of the SOI since the SOI intervention is an information system focusing on specific aspects of the SOI. It is evident that an information system alone cannot achieve all necessary tasks in the SOI by itself but can support and improve the execution of certain system functionality. The process analysis and desk research have led to a specific set of functions in the SOI, which can be improved. These functions are coloured in purple and can be found in Figure B.3. Walden et al. (2015) refers to specifying the system's functionality designated for intervention as defining the system boundary. The system functions prone to be improved by the intervention are presented in purple in Appendix B Figure B.3: Information system functionality. Therefore, this section's desk research and interviews specifically aim at deriving requirements for the information system and not the overall SOI. Desk research was used to derive information on stakeholders who could not be interviewed. This is reasoned by stakeholders refusing to participate in interviews or not responding to the request. The European Union and the Dutch Government were not contacted due to various public regulatory documents available, which were reviewed by the author. The Rwandan Department for Cybersecurity did not respond to the request, and the GoldStandard and SustainCert refused participation in an interview. Therefore, all institutional stakeholder information and derived requirements originate from documents published by the corresponding stakeholder. Interviews were conducted with the project developer, namely the FCF, the fuel provider (BioMassters), the cookstove provider (MimiMoto) and a purchasing party. The author could not interview households in Rwanda due to data privacy regulations prohibiting interview practices. Therefore, desk research was conducted reviewing the literature on clean cook stove projects in the African region to derive requirements from the perspective of households.

4.2. System Requirement Elicitation

This section provides information on the stakeholders' requirements of the SOI. The conditions outlined in this section are derived concerning the case presented by the FCF. For initiatives in sustainable finance that will be implemented in various contexts, the requirements must be reevaluated and modified where applicable. The following subsection differentiate requirements into functional (RF) and non-functional (RNF) requirements, where functional requirements specify what a system or product should do, defining its core functionalities and features. In contrast, non-functional requirements outline how a system should perform, including criteria related to performance, security, usability, and other quality attributes which are also defined in this chapter. A table presents the derived requirements organised according to their source Table C.2.

4.2.1. Project developer

RF1.1 The system must collect, manage, and verify carbon emissions data from cookstoves. This requirement aligns with the project developer's requested core functionality of the system. What is referred to as carbon emission data is the data required to calculate carbon emission reduction. The data required to do so is the running time of the used cookstove in households (Interview I1 section C.2).

RF1.2 The system must enable data analysis to identify inconsistencies and to enable project assessment and carbon credit calculation. Data analysis functionalities are desired to gain insight into various topics. However, the main focus of analysing data is the detection of outliers. Outliers can indicate errors and anomalies in the system. Aggregated cookstove data must also serve as input to assess the performance of projects.

RF1.3 The system must reimburse project subjects financially. This requirement aims to facilitate the functionality of the overarching system. The project developer highlighted the importance of the functionality to reimburse households for emission reduction. Households will receive direct payments when the carbon credits from their cookstove usage are sold. There is a clear consensus in the literature regarding the necessity of such a function to improve cookstove utilisation rates in households and to scale sustainable finance projects further (Gill-Wiehl et al., 2021)(Schlag & Zuzarte, 2008)(Vigolo et al., 2018)(Freeman & Zerriffi, 2014)(Uwamariya & Loebbecke, 2020) (Interview I1, section C.2).

RF1.4 The system must transparently show all financial flows in the process of carbon credit issuance. A core belief of the project developer is to be transparent on financial matters of carbon credits. The project developer requests that all costs incorporated in the carbon credit price are dynamically calculated based on the specific project and visible to all stakeholders

RF1.5 The system must link carbon credits to the project subject and the project subject context, such as region and community. Transparency is also desired concerning the origin of carbon credits. Per credit, all information such as which specific household is responsible for the carbon reduction, who this household is comprised of and where the household is located should be linked to the carbon credit (Interview I1, section C.2).

RNF1.6 The system must facilitate scalability to encompass all future projects. Clean cookstove projects are deployed in various countries by the project developer and also by other project developers (Vigolo et al., 2018). Therefore, the system must be scalable to incorporate all projects deployed by project developers (Interview I1, section C.2).

RNF1.7 The system must facilitate the certification process for carbon credits, adhering to standards such as the Gold Standard and Fair Trade Climate Standard. The certification by Gold Standard and the acquainted verification body is a requirement originating in the positive reputation of the Gold Standard. The gold standard methodologies provide the most accurate standard for carbon credit issuance in clean cooking projects (Kreibich & Hermwille, 2021) (Interview I1, section C.2) (Interview I2, section C.3).

RNF1.8 The system must collect data from cookstoves in near real-time, or at least in reasonable intervals of 2-4 weeks. The information system aims to improve various processes in issuing carbon credits in sustainable finance projects. One current issue in these projects is the delayed issuance of carbon credits. To reduce the issuance time, data must be collected more frequently (Interview I1, section C.2).

RNF1.9 The system must be user-friendly and self-explanatory for easy access by project participants. The information involves the cooperation of multiple stakeholders. Role inhabitants of stakeholder positions are subject to change, such as in the case of the purchasing parties. This means that not all stakeholders can be excessively trained to use the system, resulting in the need for a self-explanatory and easily accessible information system.

4.2.2. Funding parties

Although no funding parties were formally questioned for this master's thesis research, it is presumed that they will not impose any restrictions on the information system. It is not considered essential. The reviewed literature on clean cooking projects, did not hint at any needs from the funding party's side, and none of the interviewed parties did either.

4.2.3. Cookstove provider

RF3.1 The system must enable data analysis for predictive maintenance analysis. It is desired by the cookstove provider to derive information on the maintenance and replacement efforts of cookstoves. The data on exact cooking time is expected to help with more accurate decision-making on maintenance and cookstove replacement cycles (Interview I3, section C.4).

4.2.4. Fuel provider

RF4.1 The system must enable data analysis to target project application areas more successfully. It is desired that project performance, mainly using cookstoves, is aggregated and put into perspective with the socio-economical context. This analysis can be used to scope out communities for clean cookstove projects better. Past experiences by the fuel provider have led to the understanding that different socio-economical backgrounds of communities influence the probability of continuous cookstove usage and acceptance. The additional insight is expected to be valuable for scoping communities for sustainable finance projects (Interview I4, section C.5).

RNF4.2 The system must ensure free, prior and informed consent processes with people and local communities. It has been highlighted by the fuel-providing party that the acceptance and probability of successful introduction of SOI intervention strongly depends on the community consent ahead of SOI intervention (Filewod et al., 2023) (Interview I4, section C.5).

4.2.5. Project subject

RNF5.1 The system must align with the local payment mechanisms. The need for a financial reimbursing mechanism in the information system is the reason for this requirement. It needs to be ensured that nearly fully automated reimbursement is possible. This requires to be compatible with the financial transaction system used locally. In the context of Rwanda and the sub-Saharan region in general, this is mobile payment. Mobile payment works by connecting individuals' "bank accounts" to a mobile phone and the individual's identity (Uwamariya & Loebbecke, 2020).

RNF5.2 The system must be encompassed with training on its use. Such as the need for an easy-to-use system, there need to be training for more complicated use cases which cannot be expected to be understood easily by the majority of users (Jagger & Das, 2018)(Schlag & Zuzarte, 2008).

RNF5.3 The system must be affordable for low-income households. Sustainable finance projects, specifically clean cookstove projects, are set in a low-income household context. It is a crucial aspect of the system that it is affordable to the user (Jagger & Das, 2018)(Gill-Wiehl et al., 2021)(Vigolo et al., 2018).

RNF5.4The system must be easy to use and understand for users of all reasonable ages and levels of education. Households in clean cooking projects within and without the boundaries of specific communities differ in age groups, level of education and technological ability (Vigolo et al., 2018). It, therefore, is essential to make interactions between the project subject and the system as easy to understand as possible (Jagger & Das, 2018)(Diehl et al., 2018).

4.2.6. Verification bodies

A review of the requirements of standardisation organisations on sustainable finance projects has yet to show specific requirements for the proposed information system. Organisations such as the Gold Standard announced that they are indeed working on such standards and the deployment of information systems to ease the process of carbon credit issuance (GoldStandard, n.d.). The Gold standard, however, provides requirements regarding remote auditing processes, which is also what the information system in parts aims to do.

RF6.1 The system must enable communication with projects subject to verification bodies. Verification bodies audit projects in certain intervals. The gold standard provides the option to do these audits through remote means. It is required that the information systems provide all information to the auditor and connect the project subject with the verification body in case of the need for a remote audit (GoldStandard, n.d.).

RNF6.2 The system must document and provide evidence of the agreement mentioned in R6.3. The requirement refers to the need to document agreements between stakeholders and specifically the agreement mentioned in RNF6.3 (GoldStandard, n.d.).

RNF6.3 The system must be subject to a mutual agreement between the project developer, verification body and project subject for using it in remote assessments, following

information security, data protection, and host country regulations. It is required by the standard that contracts need to be in place to ensure that all involved parties are informed and agree on the functioning of the information system (GoldStandard, n.d.).

4.2.7. Purchasing parties

RF7.1 The system must provide project impact visualisation. Impact visualisation refers to the system's functionality to provide more detailed insight into the impact of carbon credits. It is known to the purchasing party that a carbon credit represents the removal or reduction of one tonne of carbon emission. However, it is desired to understand how, where and by whom the removal or reduction occurred (Interview I2, section C.3).

4.2.8. International Institutions

The European Institutions provide four primary policy documents; however, for this research, only the core document is analysed for high-level system requirements—namely, the General data protection regulations (Tamburri, 2020). High-level requirements, also called design principles in the field of information system research (Gregor & Hevner, 2013), are used to ensure compliance of the information system under design when operational. This is called privacy by design and is a principle originating in the field of systems engineering (Tamburri, 2020). The other relevant documents, which have to be thoroughly reviewed in case of system deployment, can be found in Appendix B in the system context diagram. However, these documents impose relatively fine-grained regulations compared to the high-level design principles in the GDPR. Therefore, further analysis of the other policies provided by the European Institutions is necessary to derive requirements; however, since this research tries to provide a general high-level reference architecture for sustainable finance projects, a relatively high abstraction level is chosen.

General Data Protection Regulation The General Data Protection Regulation applies to information systems data privacy. It aims to give people more power over their data. Organisations must handle data more responsibly, obtain informed permission, report breaches, and face harsher fines for infractions. It applies to businesses that handle the data of EU citizens both inside and outside the EU. Enhancing privacy rights in the digital age is the aim. To ensure GDPR compliance of information systems, researchers such as Tamburri (2020) suggest making use of the GDPR principles for software development (Perera et al., 2019). These principles are elaborated on in the following paragraphs. It is worth highlighting that the GDPR defines three key roles. Firstly, the data subject refers to the individual whose personal data is collected, processed or stored. Secondly, the data controller is the entity that determines for what purpose and how the personal data is processed. The last role is the data processor, which is the entity that processes personal data on behalf of the data controller. The terminology used by the GDPR is also adopted by the national institutions Rwanda and the Netherlands ("Netherlands - Data Protection Overview", 2023)("Rwanda - Data Protection Overview", 2023). In addition, the GDPR assigns rights to the data subject, which also serves as a high-level requirement. The rights specifically focus on specific features the system needs, making them essential for the system design (Perera et al., 2019).

Principle: Lawfulness, fairness and transparency Lawfulness in data processing refers to having a legal basis for it, as defined in GDPR articles 6-10. GDPR Article 6(1) outlines six legal reasons for processing data. Transparency means informing individuals about data processing (Art. 13 and 14). Data subjects should easily know processing details, purpose, controller, and rights—understandability matters, especially for minors. Fairness involves processing data in a non-harmful way, considering context. This principle safeguards the integrity and prevents discrimination (Negri-Ribalta et al., 2022)("EU - Data Protection Overview", 2022).

Principle: Purpose limitation Purpose limitation refers to gathering and processing personal data only when a clear and valid reason exists. The data must have a specific purpose. This links to transparency and the right to be informed (Art. 13 and 14). Purpose limitation is crucial for handling minors' data and sensitive categories, ensuring processing is based on clear and valid reasons rather than unnecessary collection (Negri-Ribalta et al., 2022)("EU - Data Protection Overview", 2022).

Principle: Data minimisation Data minimisation involves collecting and processing personal data only to the extent necessary for the intended purposes. The goal is to use the least amount of data possible. This approach also emphasises using fewer personal data when achieving a feasible goal without it, limiting data access, employing advanced security measures, and avoiding unnecessary copies. It is crucial for sensitive data, considering risks and context, such as when dealing with minors or power imbalances. Data minimisation is crucial for all data types, but even more so for sensitive categories (Negri-Ribalta et al., 2022)("EU - Data Protection Overview", 2022).

Principle: Accuracy and Storage limitation Accuracy and Storage Limitation are distinct yet interconnected principles. Accuracy involves maintaining precise and current personal data through reasonable measures, including rectification when contested (Right to Rectification, Art.16). In contrast, Storage Limitation mandates not retaining data beyond necessity. Defining retention periods, informing data subjects, and establishing deletion procedures are crucial. The right to erasure (Art.17 and Art.19) aligns with this principle (Negri-Ribalta et al., 2022)("EU - Data Protection Overview", 2022).

Principle: Integrity- and confidentiality Integrity and confidentiality are about securing data processing according to its risk level. Controllers must implement measures based on purpose, context, data type, and risk. GDPR mandates both controller and processor to safeguard data's integrity, confidentiality, and resilience. Measures should encompass technical, organisational, and policy aspects (Negri-Ribalta et al., 2022)("EU - Data Protection Overview", 2022).

Principle: Accountability Accountability is the principle that, at its core, is the sum of all previous GDPR principles. The idea is that organisations should be held accountable for their actions (Negri-Ribalta et al., 2022)("EU - Data Protection Overview", 2022).

The GDPR principles are translated into the system design by comprehensively formulating functional and non-functional requirements. Functional requirements articulate the specific capabilities the system must possess to incorporate GDPR principles, such as enabling users to access and rectify their data. Non-functional requirements address aspects like data encryption and access control, ensuring that the system performs in accordance with GDPR's privacy and security principles. This approach ensures that the fundamental principles of GDPR are effectively integrated into the system's structure and operation. Design principles are concepts known to design science research but are a foreign concept to the system engineering methodology applied by the author. Therefore, design principles are translated to system requirements, as mentioned above.

RF8.1 The system must maintain documentation and demonstrate compliance with GDPR principles and regulations. The system must maintain documentation on all processes to be able to demonstrate compliance with the GDPR, which incorporates the adherence to the principles mentioned in the first previous paragraphs (Negri-Ribalta et al., 2022)("EU - Data Protection Overview", 2022).

RF8.2 The system must allow data subjects to request access to their data and provide it in a structured, commonly used, machine-readable format. The right to access entitles data subjects to obtain confirmation from data controllers as to whether or not their data is being processed and, if so, to access that data. Individuals have the right to request and receive a copy of their data being processed ("EU - Data Protection Overview", 2022).

RF8.3 The system must enable data subjects to request correction of inaccuracies in their personal data. The right to rectification empowers individuals to request corrections to inaccurate or incomplete personal data. Data subjects can notify data controllers of any errors in their information and have those errors corrected as soon as possible ("EU - Data Protection Overview", 2022).

RF8.4 The system must enable data subjects to request the deletion of their personal data under specific circumstances. The right to erasure is also known as the right to be forgotten. This right allows individuals to request that data controllers delete their data in certain circumstances. Individuals have the right to have their personal data erased if it is no longer required for its original purpose, if consent is withdrawn or if data is unlawfully handled ("EU - Data Protection Overview", 2022).

RF8.5 The system must permit data subjects to object to specific data processing activities. Individuals have the right to object or opt out of having their personal data processed for particular purposes. Individuals have the right to object when data is processed, even based on legitimate interests, public tasks, or direct marketing. Upon receiving such an objection, data controllers must stop processing personal data unless they can demonstrate compelling, legitimate reasons that outweigh the individual's interests, rights, and freedoms ("EU - Data Protection Overview", 2022).

RF8.6 The system must facilitate data subjects' ability to receive their data in a portable format and transfer it to other services. Individuals have the right to data portability if they want to receive their personal data from data controllers in a structured, frequently used, and machine-readable format. This right applies when data processing is performed automatically and is based on consent or contract. Individuals can then send this data to another data controller if they like ("EU - Data Protection Overview", 2022).

RNF8.7 The system must provide clear, concise, and easily understandable information to data subjects about how their personal data will be processed, including its purposes, legal basis, retention period, and rights. The right to be informed highlights the significance of open communication between data subjects and data controllers. Individuals have the right to clear, concise, and comprehensible information about how their personal data will be treated under this right. Data controllers must disclose information about the processing purpose, the data types gathered, the legal basis for processing, the retention term, and their rights ("EU - Data Protection Overview", 2022).

RNF8.8 The system must establish security measures to ensure the integrity and confidentiality of processed personal data while not storing data longer than necessary for the defined purpose. The system must have protections to preserve the accuracy and privacy of personal information processed and prevent unauthorised access. Furthermore, the system should only keep data for the time necessary to achieve its intended purpose, ensuring that data is not maintained for longer than necessary ("EU - Data Protection Overview", 2022).

RNF8.9 The system must ensure that individuals are not subject to automated decisions without human intervention and must allow them to contest such decisions. Individuals have the right not to be exposed to automated decision-making, which permits them to avoid being solely subjected to decisions made by automated systems that significantly impact them. It includes scenarios in which judgements are made without human interaction using algorithms, machine learning, or other automated procedures ("EU - Data Protection Overview", 2022).

RNF8.10 The system must be compliant with the Directive 2009/136/EC. Directive 2009/136/EC is a legislation that focuses on privacy and electronic communication protection. Websites must get informed consent from users before placing cookies or similar tracking technology on their devices unless these cookies are strictly necessary for the website's operation. The directive also emphasises the significance of user privacy by mandating clear and understandable information about the purpose of cookies and the possibility for users to withdraw their consent quickly. Its goal is to give people more control over their online privacy and data while encouraging transparency in the use of tracking technologies (“EU - Data Protection Overview”, 2022).

RNF8.11 The system must be compliant with the Data Act Proposal. The Data Act proposal seeks to develop uniform standards for data handling, protection, and governance across member countries. Individuals’ rights to their personal data are emphasised in the plan, which includes requirements for transparent data processing, user consent methods, and the right to view and control one’s data. The act also covers cross-border data transfers, supporting secure and standardised means for such exchanges while fostering innovation and economic growth through responsible data practises (“EU - Data Protection Overview”, 2022).

RNF8.12 The system must be compliant with the Data Governance Act. The Data Governance Act establishes a regulatory framework to allow data sharing while preserving data privacy and security requirements throughout the European Union. The act encourages establishing organisations that serve as intermediaries to improve data sharing across industries while guaranteeing compliance with data protection requirements. It emphasises transparency and accountability in data processing, giving people more control over their data. The legislation also creates mechanisms for international data collaboration (“EU - Data Protection Overview”, 2022).

4.2.9. National Institutions

In deploying an information system in which information is processed beyond national borders, at least two institutions play an essential role in the design of the SOI intervention. The project subject is located in Rwanda in the FCF case. On the other hand, the project developer and other stakeholders are located in the Netherlands. It becomes clear that it is required to comply with regulations in Rwanda and the Netherlands while also being compliant with international regulations such as the ones imposed by European Institutions, as stated above.

Dutch Institutions The Netherlands is part of the European Union. It has introduced the ”Dutch GDPR implementation” act, which entails the same principles as the ones given by the GDPR (“Netherlands - Data Protection Overview”, 2023). Even though the principles in the ”Dutch GDPR implementation” act are worded differently, they can be related to the same six principles and essentially have the same meaning (“Netherlands - Data Protection Overview”, 2023). In addition to the ”Dutch GDPR implementation” act, Dutch institutions also provide the ”ePrivacy directive (2002/58/EC)”. This directive mainly focuses on requirements for electronic communication and data storage of users’ behaviour (Leenes & Kosta, 2015). These requirements correspond to a lower requirements abstraction level and are not the focus of this research. It, however, is essential to consider in practical projects. To conclude, the high-level requirements given by the European Institutions are equal to those given by Dutch Institutions.

RNF10.1 The system must be compliant with the ePrivacy Directive (2002/58/EC.) The ePrivacy Directive (2002/58/EC) is a legislation with a similar aim as the European Directive 2009/136/EC. It focuses on electronic communication and requirements for such.

Rwandan Institutions As stated above, Rwanda is the country where the project subjects are located, and therefore, the SOI handles information on Rwandan citizens. Rwanda imposes three central policies regarding information systems. Namely, the "Relating to the Protection of Personal Data and Privacy Law No. 58/2021", the "Relating to Access to Information Law No. 4/2013", and the " Governing Information and Communication Technologies Law No. 24/2016". Similarly to the Dutch Institutional documents, only one, the "Relating to the Protection of Personal Data and Privacy Law No. 58/2021" ("Rwanda - Data Protection Overview", 2023), formulates high-level design principles, while the other two provide more fine-grained requirements. Therefore, the other two documents should be addressed for this research and highlighted so developers know which policies need to be considered in practical system design efforts. However, even though Rwandan Institutions impose the exact high-level requirements on the information system, there is a crucial difference in the collection, processing and storage of data from Rwandan citizens. Rwanda requires data controllers to register with the National Cyber Security Authority ("Rwanda - Data Protection Overview", 2023).

RNF9.1 The data controller in the system must be registered with the Rwandan Cyber Security Authority. As previously mentioned, the collection, processing or storage of data of Rwandan citizens requires registration with the Rwandan Cyber Security Authority. The registration is valid for a specific purpose of data collection, processing or storage ("Rwanda - Data Protection Overview", 2023).

RNF9.2 The system must comply with the Communication Technologies Law No. 24/2016. In Rwanda, the Communication Technologies Law No. 24/2016 sets a legal framework for regulating communication technologies nationwide. The law establishes guidelines for administering and licensing communication services and equipment. In the context of communication technologies, it addresses cybersecurity, data protection, and consumer rights issues. Furthermore, the law outlines standards for dealing with cybercrime and promoting responsible and secure use of digital communication platforms in Rwanda ("Rwanda - Data Protection Overview", 2023).

4.3. Requirement Classification

Requirements can be classified into two separate classes—functional and non-functional requirements. Functional requirements typically describe the system's functionality. Non-functional requirements are often further broken down into subcategories (Kurtanović & Maalej, 2017). Desk research and interviews have led to the elicitation of various requirements, which must be classified to derive a functional architecture of the information system in the next chapter. The functional requirements mainly serve as an input for the functional architecture. However, it is essential to consider non-functional requirements in an early system development phase to reduce the risks of making design decisions without aligning with non-functional requirements (Kurtanović & Maalej, 2017). The classification resulted in 15 functional requirements, determining the system's functionality, while 22 are non-functional.

Within non-functional requirements, a further classification exists to delineate the various facets of system performance and adherence. An overview of the classification is shown in Table 4.1. One primary category in this classification pertains to the system's scalability; the pinpointed requirement generically mentions the need to scale up the system within but not exclusive to the context given in the FCF case. Another distinct cluster of requirements emerges from the imperative need to conform to established regulations, thus, the "compliance requirements." These are extracted from legislative documents, and even those deemed less relevant are referenced to ensure comprehensive analysis in practical application. Notably, a significant portion of compliance requirements emanate from the institutional stakeholders of the system. While institutions do indeed impose functional requirements on the system, a substantial proportion of their requirements revolve around non-functional aspects, underlining the importance of regulatory compliance with functionality in the early system's design. Performance requirements, on the other hand, delve into the precise performance expectations of the system. This encompasses the specification of data collection intervals and an emphasis on minimising both initial and ongoing costs for project subjects. Usability requirements aim towards optimising the user-system interaction. They delineate the specific nature of these interactions and the user experience, ensuring that it aligns seamlessly with user expectations and needs. Furthermore, a substantial cluster of requirements centres on the intricate system deployment process. These requirements outline the various stages and states involved in the system deployment process, pinpointing specific tasks and deliverables that must be meticulously executed to ensure a successful deployment. Additionally, two requirements pertain specifically to the interface between the reimbursing functionality, local financial transaction services and the information systems used by stakeholders.

Table 4.1: Requirements grouped according to type.

Functional requirements		Non-functional requirements (Scalability)		Non-functional requirements (Compliance)		Non-functional requirements (Performance)		Non-functional requirements (Usability)		Non-functional requirements (Process)		Non-functional requirements (Interface)	
RF1.1	The system must collect, manage, and verify carbon emissions data from cookstoves.	RNF1.6	The system must facilitate scalability to encompass all future projects.	RNF1.7	The system must facilitate the certification process for carbon credits, adhering to standards such as Gold Standard and Fair Trade Climate Standard.	RNF1.8	The system must collect data from cookstoves in near real-time, or at least in reasonable intervals of 2-4 weeks.	RNF1.9	The system must be designed to be user-friendly and self-explanatory for easy access by project participants.	RNF4.2	The system must ensure free, prior and informed consent processes with people and local communities.	RNF5.1	The system must tie in with the local payment mechanisms.
RF1.2	The system must enable data analysis to identify inconsistencies and to enable project assessment and carbon credit calculation.			RNF8.8	The system must establish security measures to ensure the integrity, and confidentiality of processed personal data while not storing data longer than necessary or needed for the defined purpose.	RNF5.3	The system must be affordable for low income households.	RNF5.4	The system must be easy to use and understand for users of all reasonable ages and levels of education.	RNF5.2	The system must be encompassed with trainings on how it is used.	RNF1.10	The system must connect with CRM and ERP systems of stakeholders
RF1.3	The system must reimburse project subjects financially.			RNF8.9	The system must ensure that individuals are not subject to automated decisions without human intervention and must allow them to contest such decisions.					RNF5.5	The system must ensure free, prior and informed consent processes with people and local communities.		
RF1.4	The system must transparently show all financial flows in the process of carbon credit issuance.			RNF8.10	The system must be compliant with the Directive 2009/136/EC.					RNF6.2	The system must document and provide evidence of the agreement mentioned in R6.3.		

R F1.5	The system must link carbon credits to the project subject and the project subject context such as region and community.			RNF 8.11	The system must be compliant with the Data Act -Proposal.					RN F6.3	The system must be subject to a mutual agreement between project developer, verification body and project subject for using it in remote assessments, following information security, data protection, and host country regulations.		
R F3.1	The system must enable data analysis for predicitve maintenance analysis.			RNF 8.12	The system must be compliant with the Data Governance Act.					RN F8.7	The system must provide clear, concise, and easily understandable information to data subjects about how their personal data will be processed, including the purposes, legal basis, retention period, and their rights.		
R F4.1	The system must enable data analysis to more successfully target project application areas.			RN F9.2	The system must be compliant with the Communication Technologies Law No. 24/2016.					RN F9.1	The data controller in the system must be registered with the Rwandan Cyber Security Authority.		
R F6.1	The system must enable communication with projects subject for verification bodies.			RNF 10.1	The system must be compliant with the ePrivacy Directive (2002/58/EC).								

RF7.1	The system must provide projet impact visualization.			RNF 11.2	The system must be in line with customs, religion, tradition and norms given in the region and community.								
RF8.1	The system must maintain documentation and demonstrate compliance with GDPR principles and regulations.												
RF8.2	The system must allow data subjects to request access to their personal data and provide it in a structured, commonly used, machine-readable format.												
RF8.3	The system must enable data subjects to request correction of inaccuracies in their personal data.												
RF8.4	The system must enable data subjects to request the deletion of their personal data under specific circumstances.												

F 8.5	The system must permit data subjects to object to specific data processing activities, including direct marketing.												
R F8.6	The system must facilitate data subjects' ability to receive their personal data in a portable format and transfer it to other services.												

4.4. Relationships

This section explains the relationships between functional and non-functional requirements. Since the functional requirements serve as the primary input to the functional system architecture in the latter step, it is fundamental to understand the relationships to non-functional requirements. These non-functional requirements further shape the ”how” of the system’s functions. While non-functional requirements can influence the system’s functions, they can also be contradicting and seem to hinder. The requirements represent different stakeholders’ perspectives on the system, and they can be expected to have contradicting interests. Therefore, all non-functional requirement groups are juxtaposed to the functional requirements. Relationships of high importance, meaning fundamentally shaping or constraining the function, are explained. However, one group, namely the non-functional process requirements, are not linked to the functional requirements. Due to the nature of these requirements, they refer to the system’s state before deployment and, therefore, before the system’s function. Hence, they cannot interact with functional requirements. These non-functional process requirements serve as input for the deployment process description of the author in the next chapter section 6.1. It must be highlighted that non-functional requirements relate not only to functional requirements but also to the overall system. Compliance requirements from various institutional stakeholders also impose requirements on all aspects of the system. The author describes the interplay between functional and non-functional requirements in the forthcoming section, highlighting the intricate web of relationships and potential conflicts between these two facets. Visual aids, such as coloured figures, are employed solely for clarity and ease of comprehension, with colours serving as visual cues to help readers discern the connections between specific functional and non-functional requirements despite having no intrinsic meaning in themselves.

4.4.1. Functional and Scalability requirements

Scalability requirements do not contradict any functional requirements. However, it is essential to highlight that the desired functionality of the system must be able to scale with additional contexts. When scaling to different contexts, contextual requirements are subject to change. Therefore, it can not be determined at this stage if scaling the system due to implementing a similar project in a different context might impose constraints or hinder the system due to changing institutional requirements, for example. However, the author expects scalability to possibly impact all functional requirements and therefore suggests a thorough analysis of these relationships when the system is scaled.

4.4.2. Functional and Performance requirements

Performance requirements fundamentally shape and constrain the functionality of the system. RNF1.8, which specifies the cookstove data collection intervals, interacts with RF1.1, which describes the system’s core functionality. The intervals in which data is collected are preferred to be near-real-time but determined to be also acceptable in intervals of up to 4 weeks. The flexibility of the project developer concerning the data collection interval originates from the

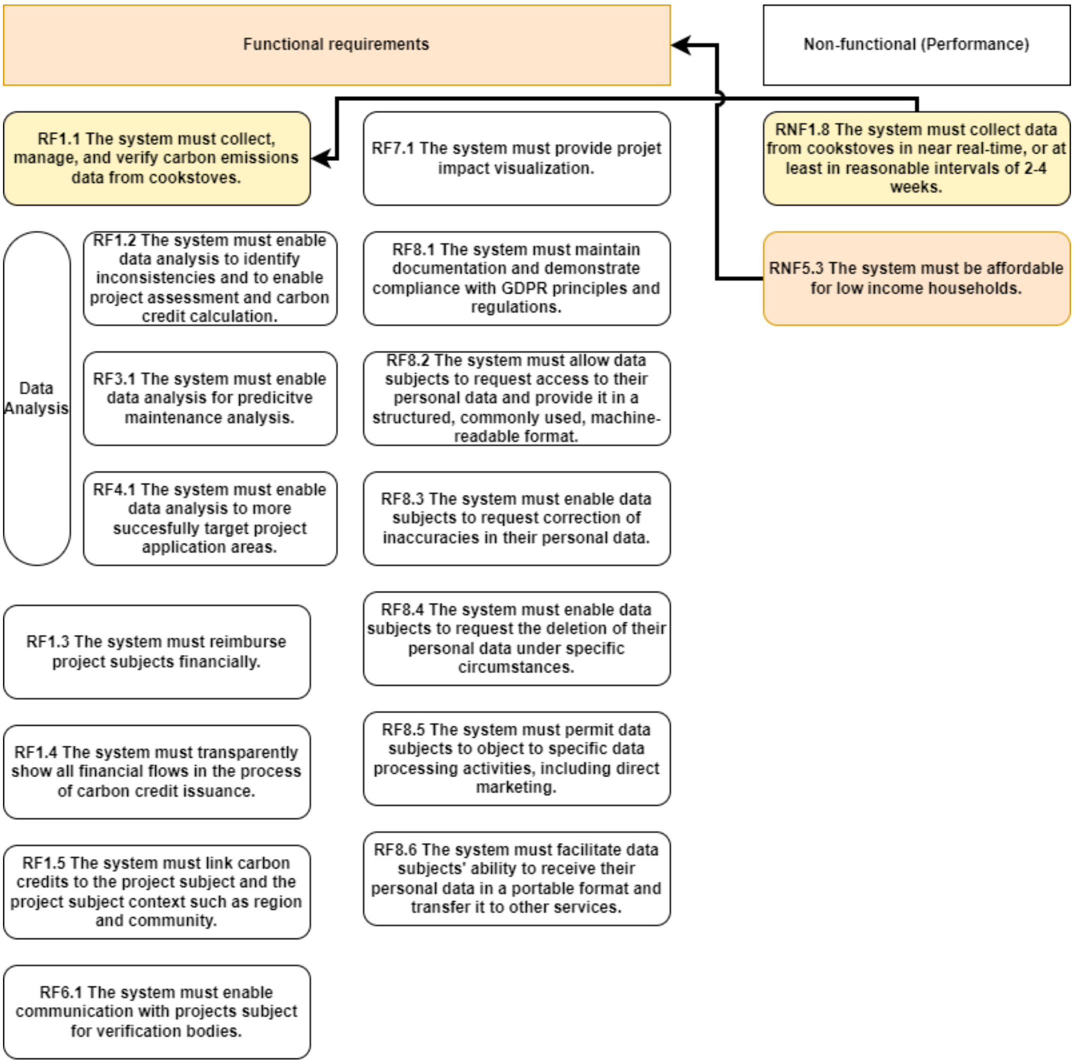

Figure 4.2: Relationships between functional and performance requirements

fact that it has yet to be determined how the system collects the data from the cookstoves. To leave room for a non-automated mean of data collection, the intervals are specified flexibly but do shape the function. The second significant influence on functional requirements is given by RNF5.3, which refers to the system's affordability. While this does not directly contradict any functional requirement, especially since no financial limits are explicitly specified, relating the functional requirements to the cost aspect is crucial when the solutions are specified to fulfil functional requirements. Therefore, RNF5.3 does influence all functional requirements.

4.4.3. Functional and Usability requirements

The two identified requirements regarding the system's usability relate to all stakeholders. However, it is worth highlighting that RNF5.4 focuses explicitly on the end users, e.g. the households. RF1.3, which concerns the reimbursement of households, is a requirement strongly affected by that. Households vary enormously in demographics, so households' technical abilities are difficult to assess. Nevertheless, the system's functionality regarding

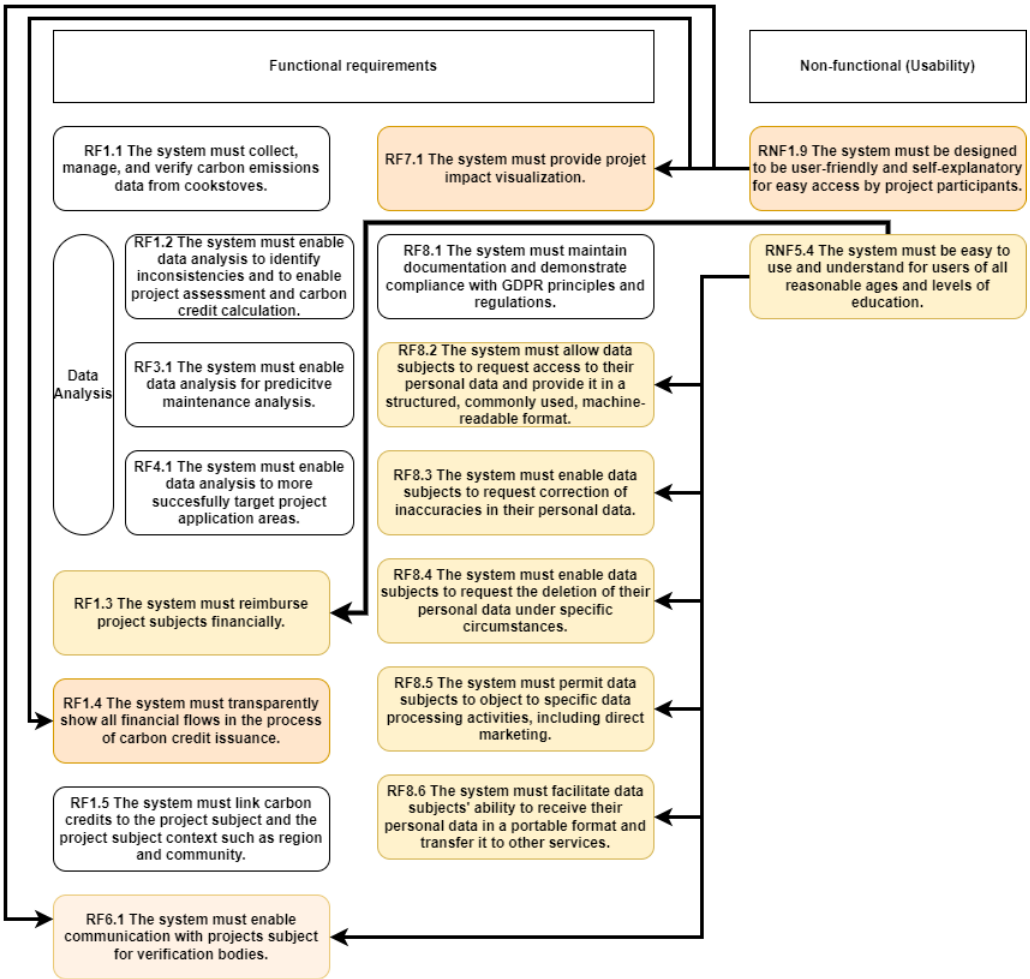

Figure 4.3: Relationships between functional and usability requirements

the reimbursing mechanism needs to be usable ideally by all households.

RF6.1, which focuses on the connectivity between project subjects and verification bodies, is also essential to usability requirements. To audit households remotely, both involved parties, the households and verification bodies, must be able to connect via the system. Since the household's technical abilities might differ, as discussed above, ensuring the function's easy usability is vital. In addition, RF8.2-RF8.6, which all concern the data subjects or the household's rights to their data in the project context, deals with the same issue previously mentioned. It must be easy for data subjects to execute functionality regarding their right on the platform, highlighting the importance of usability.

4.4.4. Functional and Interface requirements

Interface requirements define the interconnectivity to other information systems. While user interfaces are also interfaces, these requirements are specified under the usability requirements. RNF5.1 is directly linked to RF1.3. It further specifies that households' financial reimbursement must be through the local payment facilitator. RNF1.10 focuses on the interconnectivity with information systems used by other stakeholders, such as the ERP system by Odoo from

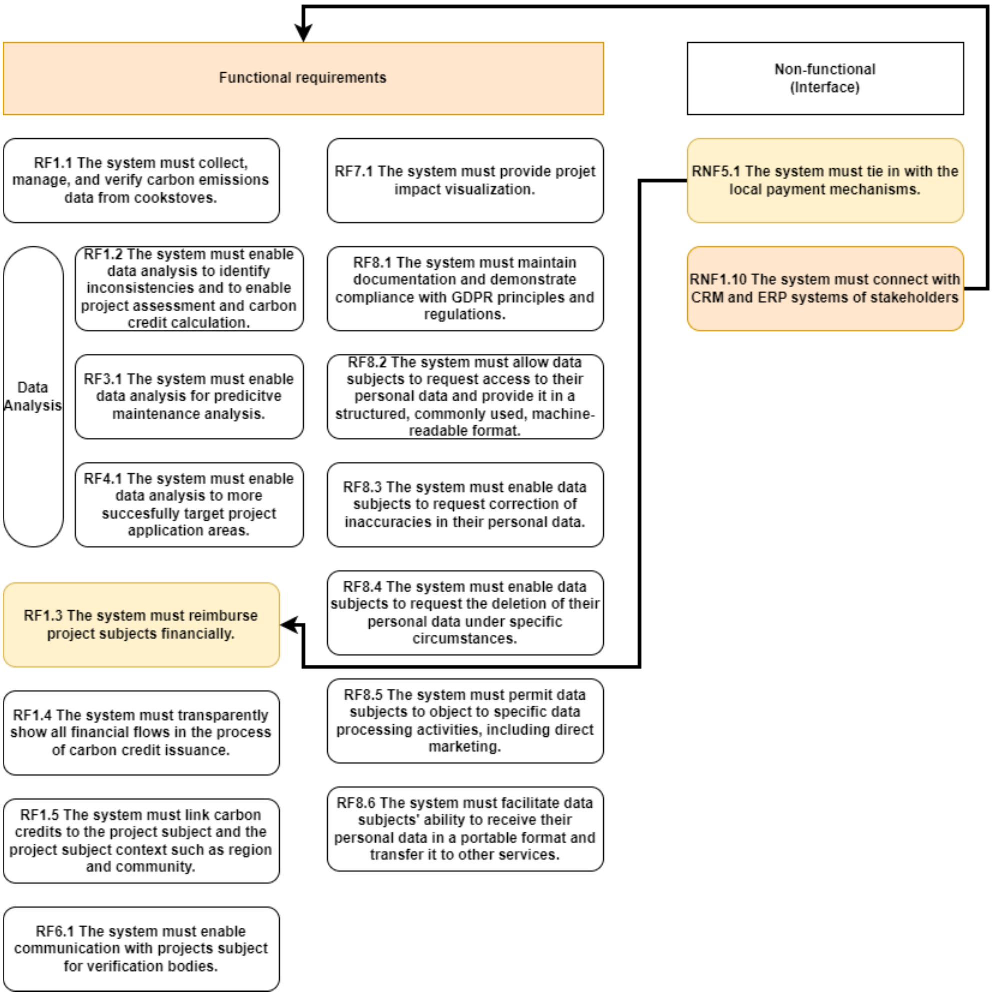

Figure 4.4: Relationships between functional and interface requirements

the FairClimateFund and the CRM system used by the fuel provider. Interconnectivity of information systems ensures seamless interaction and reduces internal efforts for data collection, processing and storage (Botta-Genoulaz et al., 2005). These requirements define the API of the system.

4.4.5. Functional and Compliance requirements

The largest group of non-functional requirements is the group of compliance requirements. While RNF8.10-RNF8.12, RNF9.2, RNF10.1 and RNF11.2 all concern the compliance with specific legislative documents and, therefore, have to be reviewed for interactions with all system functionalities in detail, there are three more specific non-functional requirements shaping or constraining functional requirements. RNF1.7 concerns compliance with the Gold Standard and the FairTrade standard. Even though these organisations do not currently impose specific requirements on an information system, they have project-relevant requirements. They are also expected to develop information system requirements in the future (GoldStandard, n.d.). RNF8.8, a requirement reflecting the data principles by the GDPR, influences various functional requirements. All functional requirements concerning data collection, processing

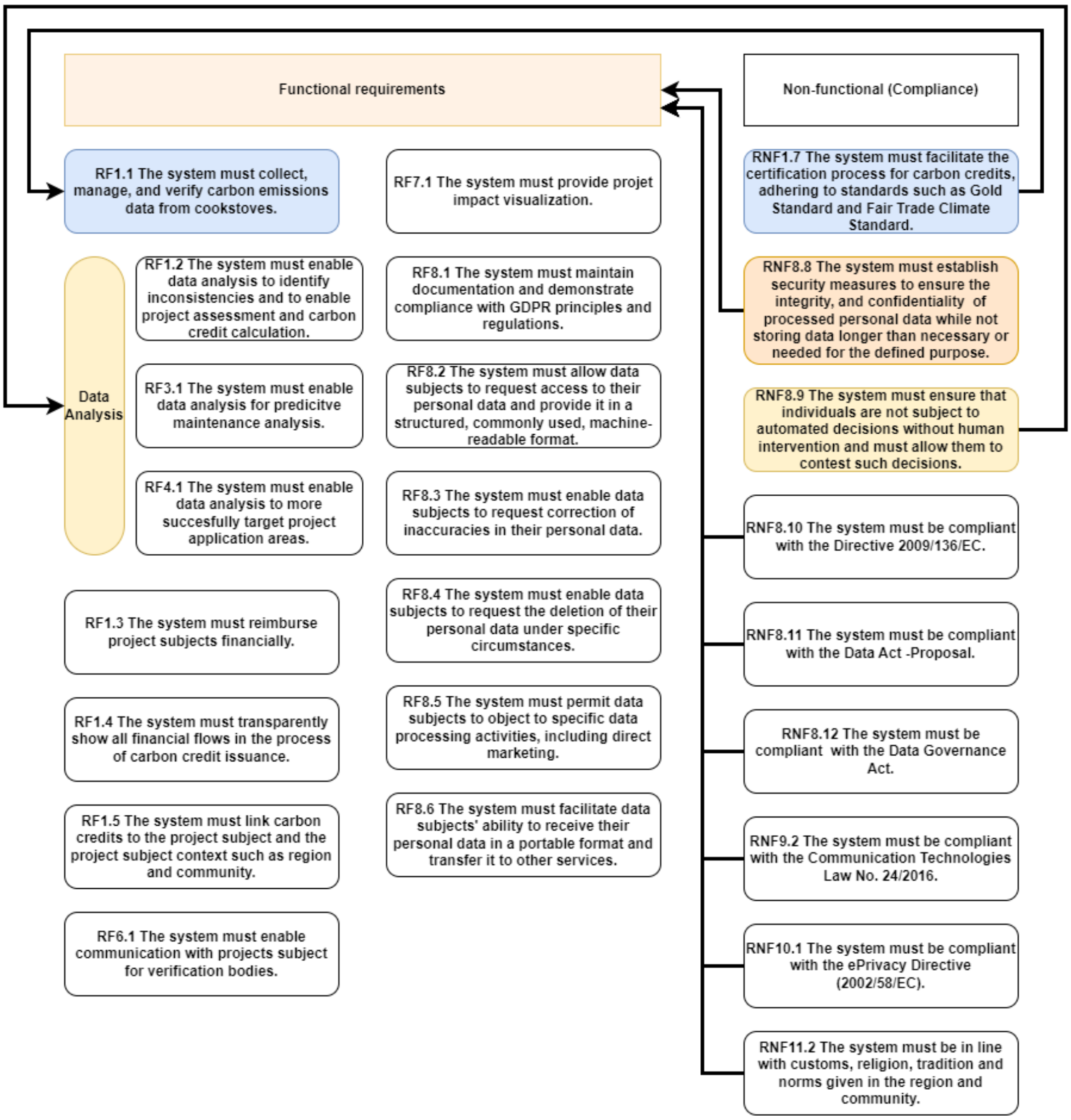

Figure 4.5: Relationships between functional and compliance requirements

and storage must be safeguarded to ensure integrity and confidentiality. In addition, functional requirements on data analysis and transparency contradict the principle that data collection should be minimised. Furthermore, it must be ensured that data subjects are not subject to automated decision-making. Hence, the insight from data analysis can only be used for automated decision-making with human interference.

4.5. Key findings

To answer the second sub-research question of this research, "Which design principles and requirements define the system?" this chapter has delved into the multi-actor defined landscape of requirements. Through exploration and the analysis of interviews, several key findings have emerged, each contributing significantly to our understanding of the requirements landscape for the system. Foremost among these findings is the prevalence of compliance-related requirements. Regulatory adherence is a significant pillar in carbon credit issuance for clean cooking projects and, therefore, also for the information system architecture. This underscores the importance of aligning the system with the regulatory framework governing information systems, emphasising the need for comprehensive documentation and the seamless integration of these requirements into the system's architecture. The chapter discovered that most functional requirements come from the project developer. These key players in sustainable finance projects contribute their experience and knowledge regarding their understanding of the workings of such programmes, providing functionality on experiences and pitfalls. That highlights the significance of their opinions in determining the system's functioning. The chapter also shows the complex network of connections that link these requirements, which reflects the complexity of clean cooking initiatives and carbon credit issuing. Understanding these dependencies for system design is essential since changing one requirement may have cascading effects on others. Due to this, requirements management must take a comprehensive approach, ensuring that changes are carefully assessed for their broader effects. As we move further, it becomes clear that the system's scalability adds complexity. The discovery shows the dynamic character of this endeavour that requirements must be reassessed in various scenarios when the system is scaled. Because scalability necessitates that the system remains flexible and responsive to changing needs, frequent evaluations and modifications to the requirements become essential to the system's lifespan. In conclusion, this chapter has highlighted the necessity of a comprehensive, compliance-centric, and stakeholder-inclusive strategy, revealing the critical elements of regulations regarding issuing carbon credits in clean cooking initiatives. The system's success depends on its ability to identify and seamlessly incorporate these requirements into its design.

5 System Architecture

This chapter is an important link in the research towards designing a comprehensive solution that aligns with the project's requirements. Building upon the previously derived requirements, this chapter focuses on creating a system architecture. Doing so addresses the sub-research question: "Which architecture designs can facilitate the specified requirements?". In the chapters preceding this one, the author identified and articulated system requirements, forming the input for the architectural design. Functional requirements are used to formulate functions representing the system's behaviour. In contrast, the non-functional requirements are partly addressed in the following chapter 6 and later in the chapter 7, serve as a retrospective means to assess the suitability of the chosen architecture and selected technologies. As the research continues to delve into the system architecture, it aims to assign functions to logical system elements, ensuring that technology suggestions can be made in the subsequent chapter. The current previous and upcoming process step is visualised in Figure 5.1.

As outlined by Holt et al. (2015) the process of developing a system necessitates a profound understanding of the problem at hand. In the context of this research, a comprehensive examination of this understanding has been conducted through a process known as context analysis chapter 3. This methodology provides a thorough grasp of the intricacies surrounding the problem. Moreover, in addition to comprehending the problem itself, it is imperative to capture the perspectives and requirements of the various stakeholders involved in the system. This critical aspect was expounded upon in the preceding chapter, as presented by Walden et al. (2015). This chapter uses the findings from the context analysis and stakeholder requirements. This information is harnessed to establish a system architecture, a pivotal step in the system development process. In systems engineering, an architectural design is defined as a model primarily considering the system as a holistic entity. It delves into how the system's functions are distributed among its various subsystems, emphasising relationships between them (Holt et al., 2015). For this research, we consider the information system as a subsystem within the broader SOI. However, during the architectural design phase, the information system takes the overarching system's role, further divided into its interrelated subsystems. It

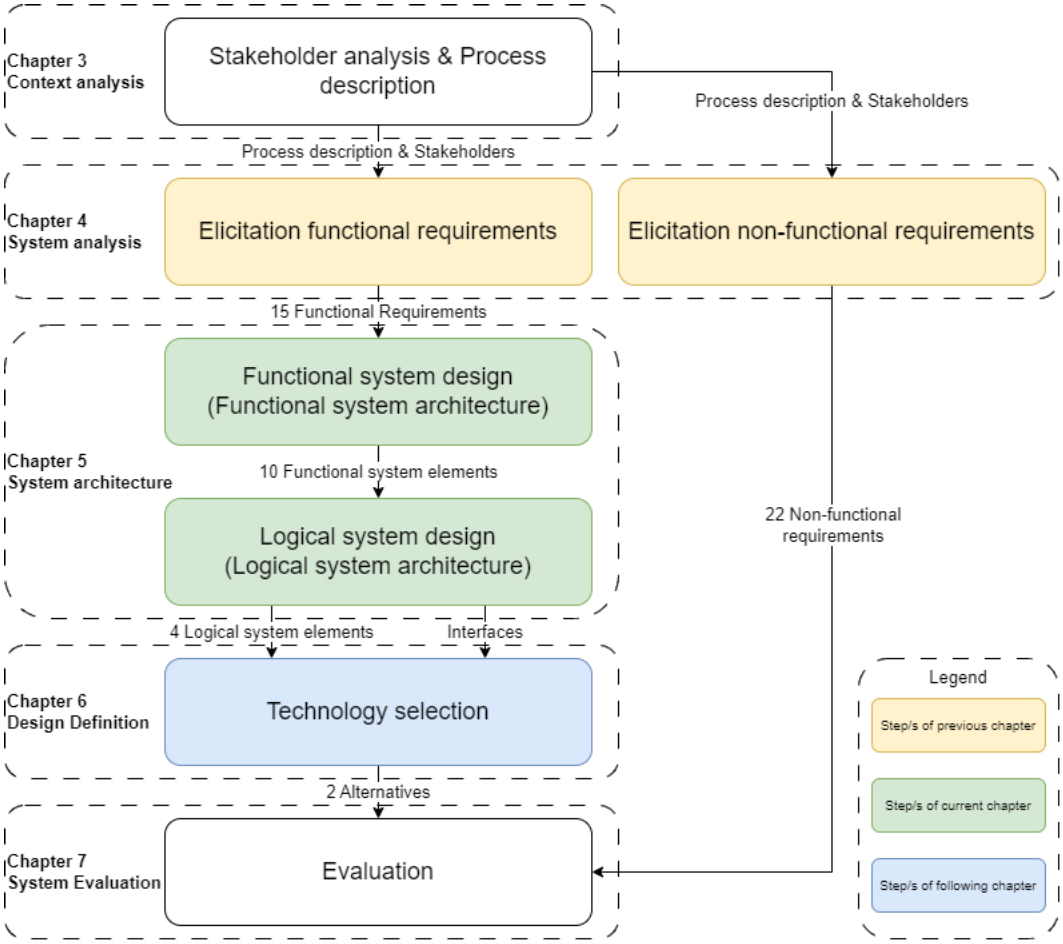

Figure 5.1: Process model

is important to note that architectural design operates at a high level of abstraction, offering a conceptual view of the system's structure and functionality (Holt et al., 2015). In practice, the architectural design is later enriched with a detailed design phase, where the focus shifts to a lower level of abstraction, providing a more granular view of the system's components and their interactions. However, in the context of this research, a deliberately high level of abstraction is maintained to facilitate easy adaptation to a variety of real-world scenarios. Walden et al. (2015) refer to this as the architecture definition process, which helps to create a global solution. The architecture is expected to have characteristics satisfying contextual and stakeholder requirements that represent the problem. The architecture also must be traceable to these requirements (Walden et al., 2015).

The architectural design in the following sections uses two different types of system elements. Firstly, functional requirements are reviewed and used as input for segmenting the information system into functional system elements. As a second step, the functions are allocated to logical system elements. These logical system elements represent abstract concepts of parts of a system. These elements are still solution-independent and serve as a logical grouping of functional system elements (Holt et al., 2015). A third type of system element is recognised in the literature, and that is the physical system element to which functions are assigned in practice. On the other hand, the research does not use that kind of system element because physical system elements define solutions for requested functionality, and the scope of this research does not include a fully specified solution but a conceptual system architecture. The generation of different system views is referred to as the "representation of a system according to different purposes" in the field of systems engineering (Walden et al., 2015). Depending on how these views are defined, they can either represent the viewpoints of stakeholders or, as in the case of this research, functional and logical viewpoints of the system (Kossiakoff et al., 2020). This research uses the systems segmentation into functional and logical system elements since it aims to be understandable by stakeholders of various backgrounds who are not experts in specific domains. They establish an understanding of the viewer following the subject's interest. The developers of information systems are expected to use the established views in addition to creating their own domain-specific views of the system. All of the system's functional and logical components are traceable back via their indexes to satisfy the need for traceability to system requirements that were previously mentioned.

5.1. Functional system elements

This section describes the architectural design of the system from a functional view. Holt et al. (2015) defines a function as the execution of one or more functions that satisfy one or more requirements. At this point, it is noteworthy that the to-be-satisfied requirements are functional requirements. The review of functional requirements has led to the discovery of ten functions the architectural design encompasses. The functions that the system must perform within the functional system architecture are formulated using the previously identified functional requirements as the fundamental blueprint. These features and capabilities of the system are carefully created to match the requirements, ensuring that they directly correspond to the stated user needs and operational goals. This shift from requirements to functions denotes a critical stage in the system design process, where abstract specifications are converted into usable parts that collectively form a coherent and fully functional system architecture. An overview of these functions and how they interact with each other can be seen in Figure 5.2

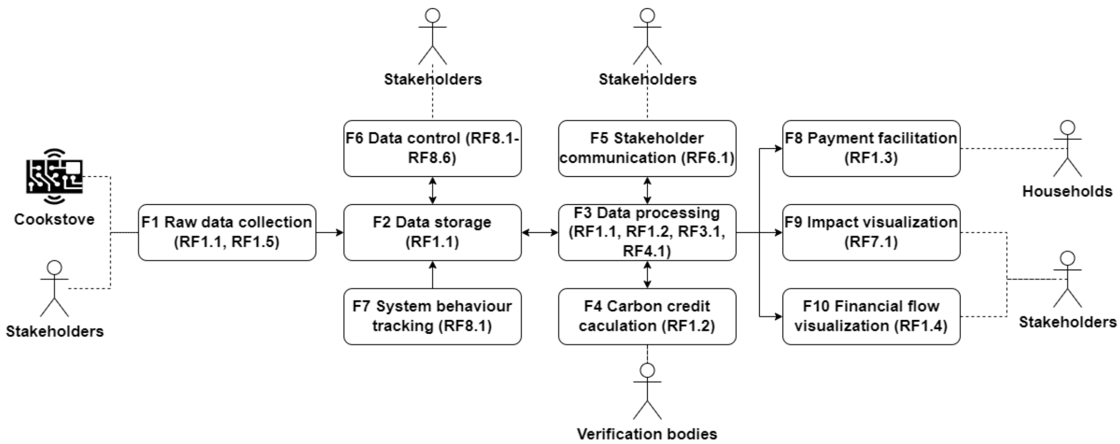

Figure 5.2: Functional system elements

F1 Raw data collection The requirements RF1.2 and RF1.5 are where the idea for the function of collecting raw data arose from. Data in its raw form is gathered from the cookstove and other relevant parties providing information. Data from the cookstove is the amount of time spent cooking. At the same time, information from stakeholders may include details about the particular cookstove, the region in which it is delivered, and the project itself.

F2 Data storage The ability to store data is a function that is explicitly requested and implicitly required by various other functions. The storing of information is necessary since it is required for collecting and processing data. It is impossible to provide the functionality of an information system without first storing the necessary information.

F3 Data processing Data processing can be traced down to one of four functional requirements: RF1.1, RF1.2, RF3.1, or RF4.1. There is a demand for data analysis functions in these four areas. It is anticipated that collecting data will make it possible to gain various insights on projects involving clean cookstoves. Some purposes of the data analysis are to enable predictive maintenance, better target project application sites for future projects, monitor the project and identify any anomalies that may arise due to the monitoring. The requirement to integrate data about pellet sales and cookstoves falls under the purview of the feature known as data processing. This is because any combination or manipulation of data streams can also be called data processing.

F4 Carbon credit calculation The system uses well-established procedures for calculating emissions, which standardisation organisations developed (GoldStandard, n.d.). These approaches consider momentarily greenhouse gas emissions and provide formulas that can be used in the computations to elicit differences from the previous situation before emission reduction procedures occurred. After the reduced emissions have been determined and compared to a baseline, hence, the previous situation, the system will compute the total amount of carbon credits that can rightfully be claimed. The function traces back to RF1.2.

F5 Stakeholder communication The communication function between the various stakeholders intends to streamline remote auditing by providing access to real-time data and is derived from RF6.1. It enables lowering the costs associated with physical presence. In addition to this, they facilitate effective collaboration between auditors and other organisations. During the entire auditing process, a function is expected to keep detailed audit trails, improving transparency and accountability (see F7).

F6 Data control This function of data control emphasizes data privacy by empowering stakeholders to regulate who has access to, alters, or displays their data in a manner that complies with privacy standards. Stakeholders can grant or revoke consent, ensuring compliance with consent-based legislation such as the General Data Protection Regulation (GDPR), which was also the main document imposing functional requirements being fulfilled by that function, as seen in RF8.1-RF8.6. They also can export their data, make corrections to it, or ask for it to be deleted, which helps promote accuracy and privacy. Notifications, requests for data access, and audit trails all contribute to a greater degree of transparency. In addition, features centring on the user, such as customisable permissions and self-managed profiles, provide a customised and secure experience while promoting trust and accountability.

F7 System behaviour tracking The information system function called system behaviour relates to RF8.1. It acts as a recorder, keeping a record of all of the activities and procedures within it. It acts as a digital audit trail, offering openness and accountability for enterprises, which helps them meet regulatory requirements and industry standards. In addition, it is quite good at recognising anomalies and suspect behaviours, which then causes warnings so that immediate action can be taken. If there is a security breach, these logs become invaluable for doing error analysis, which assists investigators in locating the source and breadth of the intrusion. In addition to supporting compliance requirements, the system helps ongoing efforts to improve business operations by locating bottlenecks, simplifying process optimisation, and improving operational efficiency and security. In the end, it is a tool that ensures compliance with organisational processes and the resilience of those processes.

F8 Payment facilitation The Payment function is related to RF1.3, which mandates that project participants be compensated monetarily and states that such payments must be made. The underlying reason for this is that participants in the project will receive a portion of the cash generated from the sale of carbon credits, which will result in a greater incentive for them to start and continue using clean cookstoves. As a result, the information system needs to identify the source of the sold credit and reimburse the household with a portion of that revenue. It is necessary to transfer the portion of the revenue to the project subject while utilising the services of the local payment facilitator to ensure accessibility.

F9 Impact visualisation The RF7.1 function that must be fulfilled can be conceptualised like a project dashboard, a prevalent term in the industry. A dashboard of this type is a tool that can visually show the impact of a project. In the project context, it can demonstrate where and how these credits are earned, making the information simple to process. It was brought to everyone's attention that geographical maps may be used to demonstrate the origin of the credits, emphasising the areas that have the most significant impact. Metrics for reducing emissions can be displayed more effectively through charts and graphs, which depict trends and efficacy.

F10 Financial flow visualisation The project developer stipulated RF1.4 as a functional requirement, which is the function that aims to reveal all financial flows in the system transparently. It was defined as having the functionality of a dashboard, which is comparable to the Impact visualisation (F9). A transparent financial dashboard within a project acts as a clear and open portal into all financial actions related to a carbon credit. This function provides an overview of the project's overall financial situation. It aims to present the sources of revenue, expenditures, and real-time information regarding sales in a way that is simple to comprehend.

Visualising financial data and gaining an understanding of patterns is made easier through the use of graphical representations. The function should encourage financial transparency and accountability, fostering confidence among stakeholders and allowing them to make decisions based on accurate information. It is envisioned as a tool for stakeholder interaction, providing an all-encompassing perspective of the flows of financial resources.

5.1.1. Functional interactions

The single functionalities represented by the functional system elements obtained from the functional requirements can be logically separated. Nevertheless, it is essential to emphasise that various functions interact, and these interactions must be defined. Interfaces are part of the logical system decomposition. Nevertheless, they do relate to functional system elements. They are essential to any system since they enable communication between humans and systems, systems and systems, or between subsystems. The interactions that take place between the functions serve as input for the process of assigning functional system components to logical system elements. These logical system elements are then improved with information regarding their required interfaces (Walden et al., 2015).

The overview in Figure 5.2 shows that most functions are related to data; out of ten functions overall, four are directly involved in data handling. These functions can be considered as interacting functions since the processing of data (F3) requires the presence of data and, therefore, the storage (F2) and, previously, the collection of data (F1). The data is sourced from two different sources: the cookstoves and the system's stakeholders. The information system then stores the data to be accessible for data processing. As a final step, the processed data is either used for the calculation of carbon credits (F4) to facilitate payment when applicable (F8) or is visualised to specific stakeholders for representation of impact (F9) or the display of financial flow (F10). System behaviour tracking (F7) collects information on all these processes and stores the information in the system (F2); data control gives all system users and, therefore, a majority of the stakeholders the opportunity to have control over their data and the data of others depending on the case (F6). Stakeholder communication is another exception that relies on the data but has a clear, logical separation (F5). The function enables stakeholders, mainly the households and the verification bodies, to communicate via the system.

5.2. Logical system elements

A logical system element refers to the abstract concept of something; they are solution-neutral and group functional system elements. Logical system elements in this research are therefore used to aggregate functional system elements and, more importantly, to identify interfaces. The benefits of this system modelling technique are that the solution-neutral logical system elements can be applied across various projects but realised differently in different contextual applications and types of sustainable finance projects (Holt et al., 2015). Following the previous decomposition of the system into functional elements and their relations, the author suggests a logical separation of the system Figure 5.3 into the four following, LSE serving as

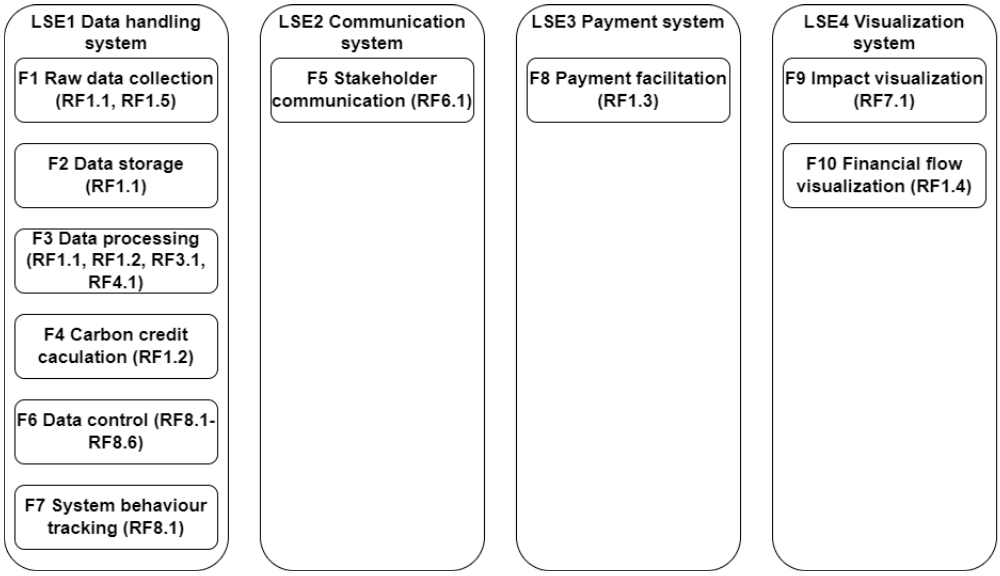

Figure 5.3: Functions grouped into logical system elements

the prefix for logical system elements:

- LSE1 Data handling system
- LSE2 Communication system
- LSE3 Payment system
- LSE4 Visualization system

Functions are grouped, e.g. into a logical system element known as the "data handling system" to streamline and centralise all activities related to data management within the overall architecture. Inspired by NASA's description (Nguyen et al., 2008) of command and data handling systems, this grouping includes functions like raw data collection, data storage, data processing, system behaviour tracking, and data control (mars.nasa.gov, n.d.). The other logical subsystems are chosen since their functionality clearly sets them apart from each other. There is no overlap in the functionality of a payment and communication system. However, it is important to highlight that all systems require the data handling system to function. Communication, payment and visualisation all require the data handling system to access, store or process data. The process of assigning logical subsystems facilitates assigning responsibilities, splitting design efforts into logical work packages and understandability of the system (Kapurch, 2010). Therefore, there is no formal structure to assigning functions to logical system elements and other functional decomposition into logical subsystems are possible.

Data handling system The data handling system is a logical system element that combines all functions linked to data into a single, cohesive whole. In light of this, the previously developed functions F1, F2, F3, F4, F6, and F7 are combined. The data handling system integrates the vast majority of the system's functions and emphasises the significance of its relevance in the information system's architecture.

Communication system The communication system incorporating F5 enables effective communication among various stakeholders. The logical system element serves a singular function, but a distinct logical system element is introduced due to its distinct functionality compared to other functions.

Payment system The logical system element payment system is comprised of F8. Like the communication system, it only facilitates one function significantly differing from others.

Visualization system The Visualisation system incorporates two functionalities, F9 and F10. These two functions, which differ in what is visualised, are still of the exact logical nature. Both functions aim at representing information to their target stakeholders, therefore being grouped under the same logical system element.

5.2.1. Interfaces

Interfaces are described by the ISO 15288 standard for systems engineering as the collection of relationships and interactions between a system's various components and across the system's boundary (Walden et al., 2015). To put it more simply, a system has internal and external interfaces, with the difference being that external interfaces cross the system's boundary, whereas internal interfaces do not. Both external and internal interfaces have their roots in requirements, such as RNF5.1 and RNF1.10, respectively. RNF5.1 refers to an interface across the system boundary when it says an interface is required with the local payment facilitator. This indicates that the interface is external because it crosses the system boundary. In addition, it details a way for systems to interact with one another. However, RNF1.10, which imposes a qualitative requirement on the interface between humans and systems, can be entirely defined by the system architect because no interface given by another system has to be considered. However, even though stakeholders did not give requirements on some interfaces or have not been discovered in desk research, stakeholders have mentioned various times that they have used information systems for various purposes for quite some time. This leads the author to introduce the necessity to consider every stakeholder who serves as a data source as an information system user also requiring connectivity to their system. Hence, an external system-to-system interface is required when stakeholders give or require information. An overview of logical system elements and their respective interfaces can be found in Figure 5.4. The green arrows indicate internal interfaces between the logical system elements, whereas the orange and red arrows indicate external interfaces across system boundaries. The red arrow represents a human interface, and the orange arrow indicates the interfaces between systems. Since the data handling system (LSE1) requires input and output from stakeholders, some data may be transferred via system-to-system interfaces, while other data will require the input of humans. It also varies from stakeholder to stakeholder whether or not a human interface or system-to-system interface is required. The same can be said for both the interfaces of the visualisation system (LSE4) and the system itself. The SOI may require a human interface or link up with the information system that the stakeholders

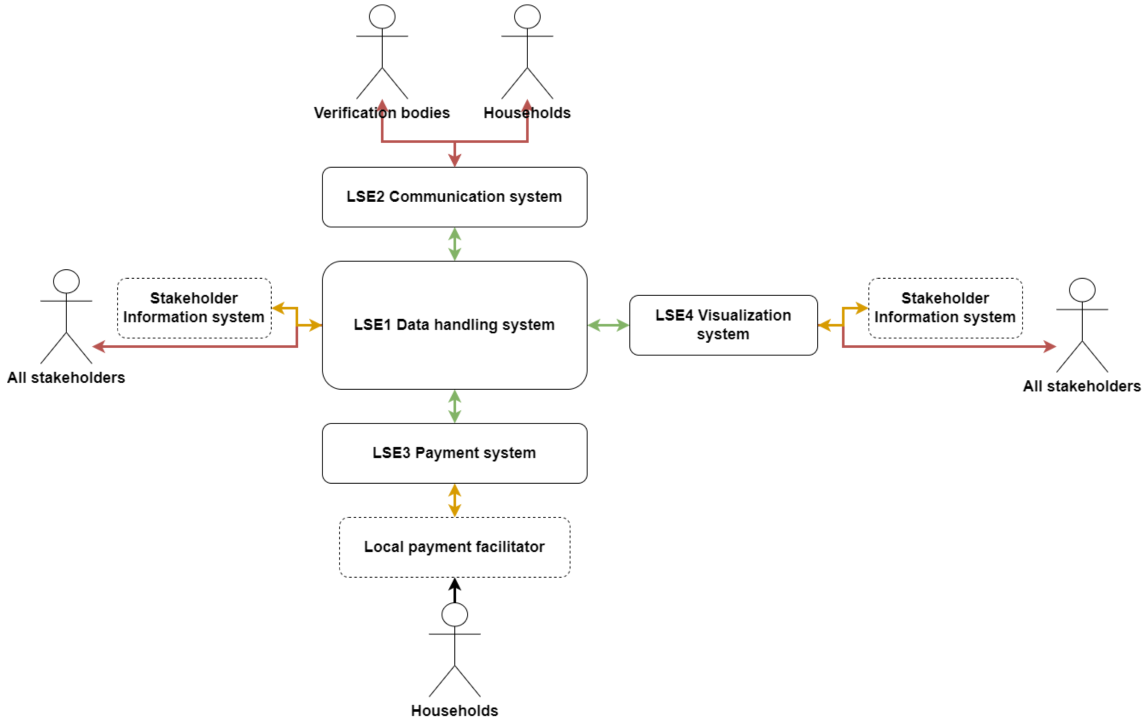

Figure 5.4: Logical system elements and their interfaces

use. Since it is not anticipated that individual households will use any information system, the household "communication system" interface does not specify a system-to-system interface. On the other hand, the payment system needs only a system-to-system interface in order to communicate with the regional payment facilitator.

5.3. Key findings

In conclusion, this chapter aims to act as an information aggregation component leading to a functional and logical system architecture per the principles described in ISO15288 (International Organization for Standardization, 2018), answering the sub-reserach question:"Which architecture designs can facilitate the specified requirements?". It uses the groundwork laid in the previous chapters, specifically the analysis of the context and the requirements elicitation. Functional system elements are crucial because they provide an overview of their behaviour and trace back to requirements, ensuring that functional system elements meet functional requirements. They contribute significantly to the process of subsequent design definition by providing an overall comprehension of how the system operates, which is provided thereby. On the other hand, logical system elements help identify interfaces within the system. Logical elements zoom in to specific interaction points, whether with other system components or external stakeholders. In addition, the chapter delves into the critical endeavour of determining which system interfaces are internal and external. These interfaces play an essential role in understanding connections between the logical system elements and the external stakeholders or systems outside the system boundary. This all-encompassing approach ensures that the system architecture addresses the internal processes it utilises and interfaces without difficulties with the larger ecosystem in which it functions.

6 Design Definition

In this chapter, we build upon the foundation laid by the previously established logical system architecture. Our focus now shifts towards researching and incorporating technologies that fulfill the functions outlined within this logical system architecture. This approach is instrumental in providing a more concrete and less abstract system architecture.By integrating technology components into the architecture, we enable the evaluation of its practicality against both functional and non-functional requirements. An exclusively functional architecture, devoid of technology considerations, may prove less insightful when evaluated in isolation. In essence, the inclusion of technology selection enriches the architectural framework, making it more robust and aligning it with the real-world context in which it will operate. According to Walden et al. (2015), the goal of the design definition phase is to ease the implementation of the system at a later design stage by giving more precise data and knowledge about the system and its constituents. The functional and logical views considered by the system architecture are enhanced with additional information during the system design phase. This is because the system architecture considers a very high level of design and represents these views as functional and logical perspectives. The valuable data pertaining to system implementation are the primary focus of the information provided in this step of the design cycle. It assigns the information to the appropriate system elements based on the findings from the steps that came before it or the results of additional research conducted with a more solution-oriented perspective (Holt et al., 2015). It, therefore, adds to the answer to the sub-research question: ”Which architecture designs can facilitate the specified requirements?” by providing more detail. Because of this, the system architecture described in the prior chapter is utilised, and additional information is provided for each logical system element. Various different technologies can be assigned to logical system elements. Depending on the level of abstraction and, therefore, the level of detail, many technologies are available. The author of this research analyses state-of-the-art technology and proposes a technology selection based on that. However, the research also provides an alternative to that by proposing and comparing a more ”traditional” system architecture. In addition to that, details on the interfaces that have been identified are

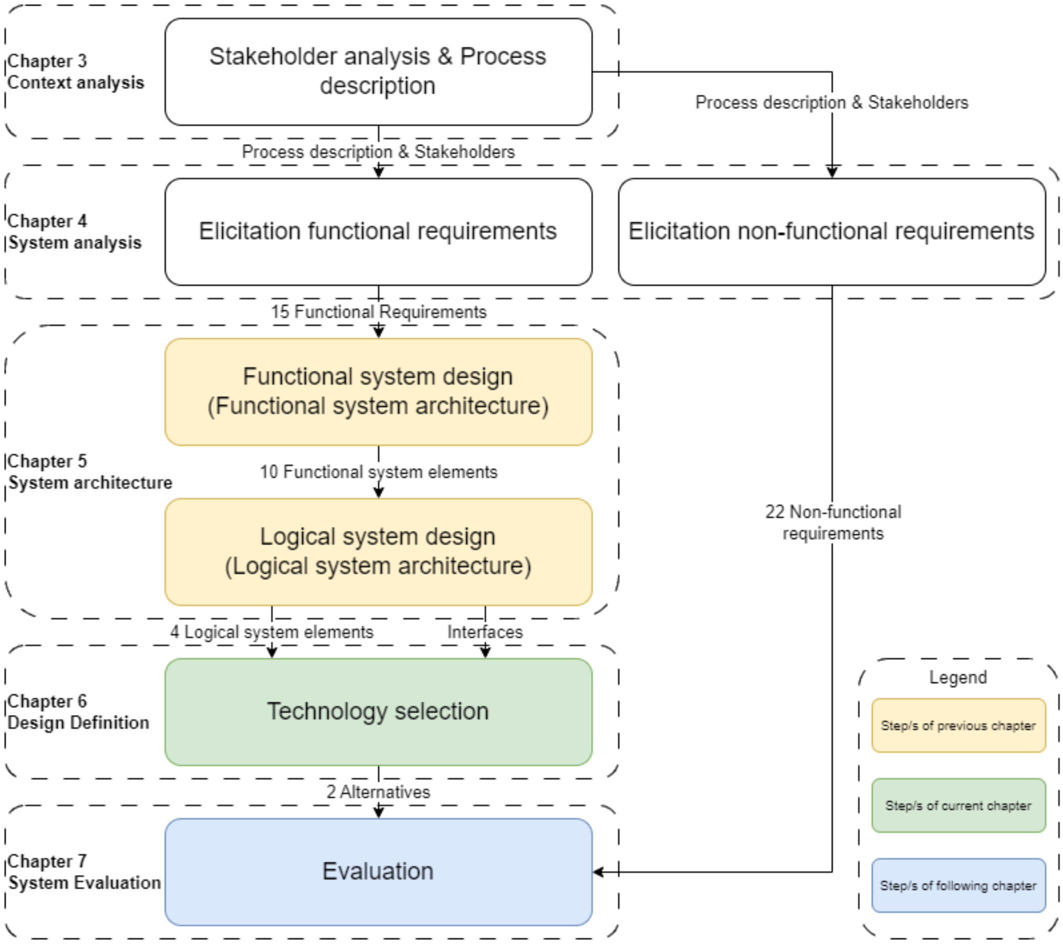

Figure 6.1: Process model

listed. These steps are executed according to ISO15288 (International Organization for Standardization, 2018), which specifies deliverables for the design definition process, such as the ”system design definition” and an ”interface definition,”. The chapter also elaborates on the system’s deployment process since requirements concerning that process were discovered in the requirements elicitation phase. System deployment, in general, is a fundamentally important aspect in the implementation phase (Walden et al., 2015). Therefore, it is also briefly discussed to ensure that a complete set of information is passed on for future consideration by stakeholders and developers. The current step in the overall process is visible in Figure 6.1. The chapter starts with a process description of the system deployment process and then describes a set of frameworks and technologies for each logical system element. Two alternatives are provided for the data handling system element, and a framework is provided to guide the decision concerning the key difference of a centralised or decentralised architecture of the alternatives.

6.1. Information system deployment

In the previous chapters, context analysis and requirements elicitation were inputs for the system architecture development. However, these chapters have also led to the discovery of ”process requirements”, which focus on the period before system deployment. In simpler terms, these are requirements not focusing on the system’s operation but on what has to be done before the system’s deployment. The discovered requirements are analysed and elaborated on to ensure possible system deployment while ensuring compliance with regulations. The requirements for the process are presented in the form of a figure, and that figure displays

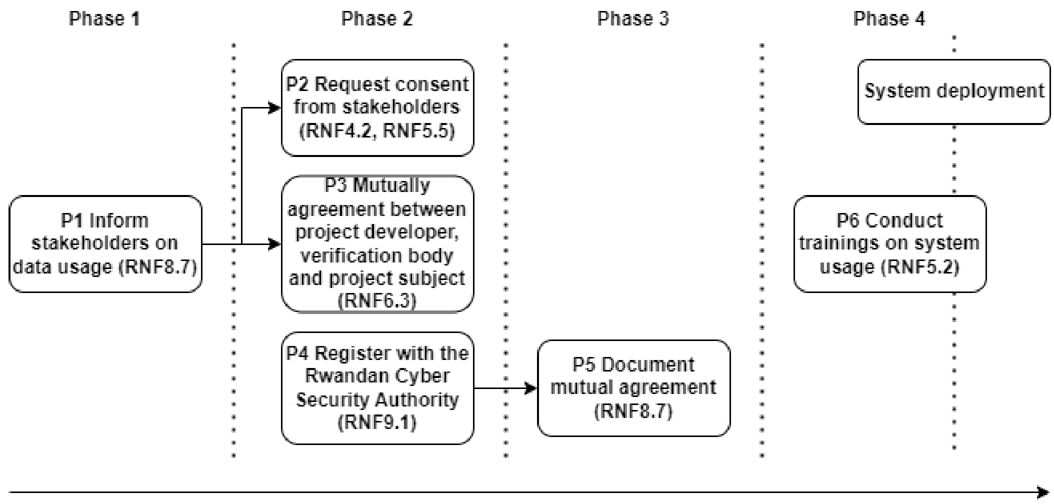

Figure 6.2: System deployment steps

a process that consists of four steps, which can be found in Figure 6.2. It is recommended that the steps be carried out in the specified sequence. On the other hand, the steps not connected by arrows are free to be carried out in any order. The total number of derived process instances is six section 4.3.

The first step, or P1, requires all stakeholders to know how data will be used. ”Data usage” refers to how personal data is processed, including for what purpose, how long the information is stored, within what legal constraints, and the rights granted to stakeholders. This step is partially derived from legislative documents. However, it also ensures that the system will be as transparent as intended by supplying information on how it will behave to various stakeholders.

P2 ensures that stakeholders have understood and agreed with the system behaviour with a specific focus on their data by requesting consent from stakeholders. This ensures stakeholders maintain control over their data by understanding the system’s behaviour.

Step P3 of the procedure for deploying the system refers to the requirement that a mutual agreement be defined between the project developer, the verification body, and the project subject. This ensures that remote auditing processes via the information system are possible and agreed upon. P5 represents the documentation requirement that corresponds to the previous process step.

Before any personal data of Rwandan citizens can be collected or processed, the specific project context of Rwanda mandates that an organisation first registers with the Rwandan cyber security authority (P4). It is necessary for the system's users, or stakeholders who will be interacting with it, to receive training on how to use it before it can be deployed. These trainings are the final step before deployment, and depending on the stakeholder, they may be started before, immediately after the system is deployed or continued later.

6.2. Information system design

The previous chapters and their findings have led to an understanding of the system functionality and logical arrangement of system elements. The problem at hand and the proposed system architecture describing the functionality hint at what is referred to as a "platform" in information systems. Though the term "platform" is not officially defined according to Inozemtsev et al. (2022), other authors would describe a platform as a set of technical elements that can be software and hardware associated with organisational processes and standards (De Reuver et al., 2018). Ben Arfi and Hikkerova (2021) mentions the importance of digital platforms to supportive knowledge sharing, and Kapoor et al. (2021) highlights that digital platforms facilitate the importance of inclusion of diverse participants in information systems. The mentioned characteristics fit well with the functional system architecture, indicating that the information system under design is a digital platform.

The information system design section considers the four logical system elements described in the prior chapter and the interfaces that correspond to those elements. As was mentioned earlier, this section aims to detail logical system parts by providing additional information while maintaining a level of abstraction that enables various solutions to be implemented. This entails not placing any restrictions on the possible solutions, which is a fundamental principle of systems engineering (Holt et al., 2015)(Kossiakoff et al., 2020).

6.2.1. LSE1 Data handling system

The data handling system can be characterised as the central element of the information system being developed. This is attributed to its essential interconnectedness with all other system elements and its encompassment of the majority of functions, as depicted in Figure 5.3. The system effectively manages all necessary data functions and establishes connections with all relevant parties. The establishment of connectedness with all stakeholders presents a range of issues, which will be elucidated in the subsequent paragraphs. These challenges encompass the use of frameworks and technologies aimed at addressing them. The "data handling system" design definitions encompass two distinct choices. The initial alternative chosen by the author suggests the integration of cutting-edge technologies, such as distributed ledger technology and multi-party computation. This alternative was chosen since state-of-the-art literature in the field of data handling presents these technologies to tackle challenges identified in the problem statement. Nevertheless, it is worth noting that the implementation of these sophisticated technologies necessitates substantial initial capital outlays (Chowdhury et al., 2018). The literature discusses the transformative impact of multi-party computation and distributed ledger technology on control, trust, and risks associated with data sharing, highlighting their potential benefits (Agahari et al., 2022)(Zhong et al., 2020). However, the issue of trust, which is closely linked to data control and risks, has been accomplished by responsible centralised organisations that are trusted to handle data. The inquiry about whether these entities, which perform the tasks assigned to the data handling system through conventional methods involving centralised control and storage, should be substituted by technology is contingent upon the specific use case and influenced by numerous factors (Chowdhury et al., 2018). In the latter sections, the researcher lists different technologies for the ”data handling system” and compares them. The sections also provide frameworks to facilitate decision-making towards one of the technology combinations.

Data Governance According to Micheli et al. (2020), the term ”data governance” is still ambiguous. However, Micheli et al. (2020) refers to it as shared stakeholder efforts to reach common decisions. The platform under design connects various stakeholders and collects, stores and processes personal and non-personal data. Functionalities of the system, such as F9 and F10, the functions related to data visualisation, require stakeholders to access other stakeholders' data. Accessing and manipulating personal data from other stakeholders is challenging, considering institutional and moral aspects. As discussed previously in the system deployment section section 6.1, it is required that arrangements on how data is used and by whom are made in advance. These arrangements ensure that stakeholders are informed and consent to the proposed data handling procedures. Even though these arrangements are made according to the GDPR requirements, such as RF8.1 to RF8.9, it is also necessary to ensure that these agreements do not oppose GDPR principles. Put in simpler terms, arrangements should align with the GDPR principles. It is of general importance to design information systems according to human values with moral connotation in mind (Perera et al., 2019). The GDPR highlights human privacy and fairness values, which are also reflected in the chapter 4. Data governance frameworks provide guidance for implementing such values, which is why the author decided to introduce them.

Data governance framework Ensuring regulatory compliance in a multi-actor socio-technical information system while addressing concerns amongst citizens regarding privacy, trust, security and others handling data requires using a data governance development framework as suggested by Alhassan et al. (2016). A promising data sovereignty governance framework providing aid for the challenges mentioned above via data classification while providing more detail for the data handling system is the similarly named framework by Singi et al. (2020). The framework concerns two significant factors in reasoning for a structured data governance approach, such as the one provided by their framework. The first is that organisations operating globally must comply with multiple laws, and the second is that these laws keep evolving. The FCF case spanning various countries and their institutions, e.g. Rwanda, the Netherlands and subsequently the European Union, reasons the proposal for the knowledge graph-based data sovereignty governance framework to derive a detailed and internationally compliant data governance procedure for the information system. In addition, the system's scalability, as requested by the FCF (RNF1.6), further strengthens the need for an adaptable platform governance design to incorporate future projects. The framework approach of data classification ensures security constraints and access rights to specific data categories and stakeholders. Figure 6.3 depicts an overview of the suggested framework. The core models are data regulations, regional and data classification. Singi et al. (2020) explains that law and regulations applicability depends on the data type. The central data type differentiation here is personal and non-personal data separation. The framework classifies the data accordingly. The regional model serves as a connecting element between the models of data classification and regulation. The 'belongsTo' and 'applicableTo' relations establish connections between the data subjects, regions, and data laws. The Data Regulation Model encompasses all of the rules that are specific to the various regions. It represents data laws, which can be rules and regulations, such as data protection and privacy, localisation, etc.. The laws are further subdivided into categories according to the data operation (storage, processing, and transfer) that they are compelled to comply with (Singi et al., 2020). While the suggested governance

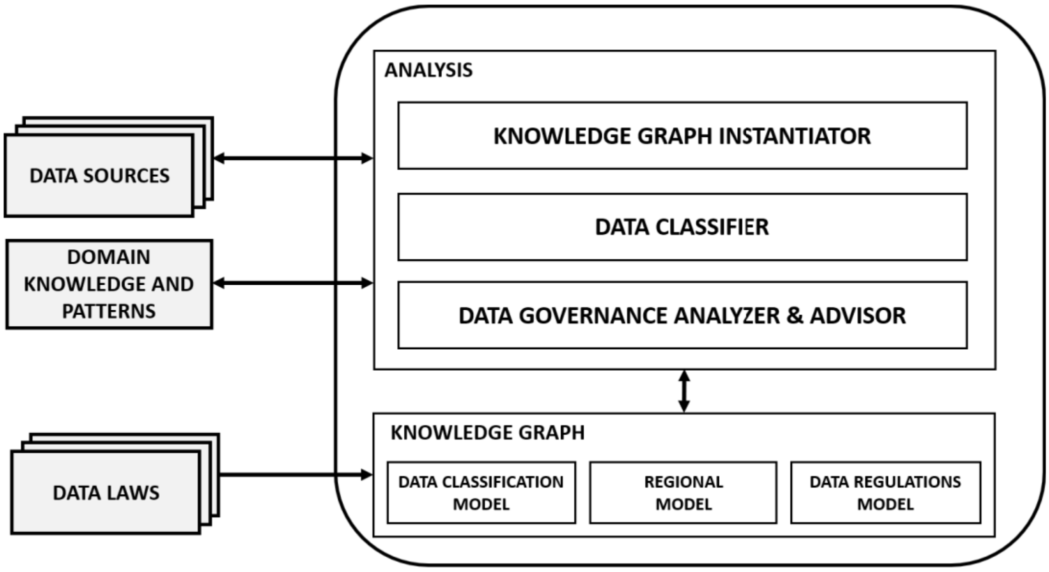

Figure 6.3: Data Sovereignty Governance Framework (Singi et al., 2020)

framework provides a solution to ensuring regulatory compliance with all involved institutions, it is important to further enrich the system with information and another data governance model focusing specifically on personal data. Personal data handling is subject to academic discussions and will be an even more relevant topic in the future, therefore requiring substantial attention (Alhassan et al., 2016). Research has identified another data governance model, which is expected to tie in well with the model by Singi et al. (2020) since its modular design can be adapted.

The identified model is a promising data governance model concerning the context in the FCF case. Personal data sovereignty (PDS) is a data governance model focusing on business entities and data subjects. Business entities and data subjects comprise the majority of non-institutional stakeholders in the FCF case. The goals of PDS are "empowered data subject”, ”economic growth”, ”private profit”, and ”knowledge sharing”. While private profit is considered not in the scope of the overarching system of carbon credit issuance, the other three goals suit the system well (Micheli et al., 2020). This Personal data sovereignty (PDS) framework extends beyond the requirements set by the General Data Protection Regulation (GDPR). In other words, it encompasses additional measures and practices beyond the minimum standards mandated by GDPR. The PDS model, in its comprehensiveness, offers an enhanced level of data protection and privacy assurance, making it more robust and rigorous than what is strictly required by GDPR.

The PDS model assigns data subjects more control over their data than traditional data governance models, specifically focusing on privacy management and data portability. Privacy management and data portability are found in the chapter 4, further highlighting the applicability of the data governance model. PDS is also recommended by the international movement ”MyData”, a conglomerate of activists, non-profit organisations, think tanks and commercial actors (Lehtiniemi & Haapoja, 2020). It tries to balance economic interests with interest in social change, hence, a move to a human value-based information system design (Micheli et al., 2020). PDS suggests so-called ”governance mechanisms,” which refer to strategies and instruments specifying how data is controlled and who can benefit from such. These strategies range from policies, contracts and interfaces to only mention the most relevant aspects of the information system under design. Micheli et al. (2020) suggests the following for governance mechanisms to achieve personal data sovereignty:

- **Principle of ”technological sovereignty”** The principle of ”technological sovereignty” describes the subject’s drive to keep ownership of related infrastructure in the case of data governance and data infrastructure (Micheli et al., 2020). An information system can refer to a separation of server infrastructure over various countries to ensure that personal information is stored in the subject country of citizenship (Maurer et al., 2015).
- **Communities and movement** Using community and non-profit efforts for privacy principles such as the ones by ”MyData,” which aims at providing individuals greater control over their data. It promotes the idea that individuals should have the right to access, control, and share their data while maintaining privacy and a secure environment. To build a more user-centric and ethical approach to data management in the digital age, MyData supports the development of technologies and practices that allow individuals to benefit from their data (Micheli et al., 2020).
- **Intermediary digital services** Users are granted the ability to save their data, acquire data dispersed over various platforms, and exercise control over how that data is shared with third parties through intermediary services. These services have been made considerably more relevant due to Article 20 of the General Data Protection Regulation (data portability). They promise to eliminate impediments for individuals who wish to exchange their data for research or other purposes, acting as trusted middlemen and boosting citizens’ ability to make decisions regarding their data (Micheli et al., 2020).
- **GDPR Right to data portability** The right to data portability, a requirement for the information system under design (RF8.6), strengthens the suggestion for intermediary digital

services. However, any other form of easy data extraction in a portable format satisfies the governance mechanism.

Some of the recommendations about the framework for personal data sovereignty may not be relevant in Rwanda because of the limited availability of technology resources. The fact that the subject of the project in Rwanda is a significant stakeholder who supplies personal data and, as a result, requires protective measures makes this a consideration of the utmost importance to take into account. However, although the framework does not provide a particular solution but recommends means for certain principles, the principles should still be considered as they contribute to the design. The combination of the suggested framework focusing on data classification Singi et al. (2020) with the personal data sovereignty model of Micheli et al. (2020) is expected to provide enough guidance for the data governance of the system. It is worth mentioning that it provides a high-level view, enriching the logical system element ”LSE1 Data handling system” with enough information for further development while staying abstract and ensuring usability for other sustainable finance projects.

Data processing and storage The requirements and principles laid out in GDPR affect data processing just as they do any other data-related function of the system. Protecting individuals' right to personal autonomy is fundamental to the GDPR. One of the six principles established by the GDPR is to protect individual privacy, which requires confidentiality and integrity of their data (“EU - Data Protection Overview”, 2022). Data integrity refers to the reliability and accuracy of the data, whereas data confidentiality aims to ensure that information is only accessible by those authorised to do so (Alhassan et al., 2016). Different actors enter several data types and retrieve data from the platform. Functions such as F1, which considers input data and functions such as F9 and F10, which require processed data to be visualised for stakeholders. Hence, data is retrieved. Since a wide variety of various stakeholders carry out these actions, it is necessary to have a method of data processing and storage compliant with the principles outlined above.

Data processing Multi-party computation (MPC) is a cryptographic approach that transforms traditional processing capabilities within platforms (Keller, 2020). Secure multi-party computation (MPC) enables the collaborative computation of functions on individual datasets while maintaining data security and secrecy and facilitating collaborative analysis. By incorporating MPC into the platform, users may participate in data-driven activities with assurance since it mitigates the risk of disclosing sensitive information. The primary advantage of MPC is its capacity to guarantee secure calculations while maintaining the confidentiality of individual participants' inputs (Goldreich, 1998). This implies that significant knowledge can be extracted from datasets without disclosing raw data, mitigating potential hazards associated with data breaches or unauthorised entry. Furthermore, integrating Multi-Party Computation (MPC) promotes the development of trust and facilitates collaborative interactions among users- (Keller, 2020). Individuals can engage in intricate data operations, including analytics, modelling, and machine learning, by utilising their aggregated data sets while simultaneously upholding stringent privacy constraints. Considering the FCF example, wherein data streams originating from cookstoves are integrated with data streams pertaining to pellet sales and afterwards connected to families' personal data, adopting the MPC approach appears to contain significant potential. Furthermore, it is imperative to monitor, trace, evaluate, and, depending on the data type, convey transparently to relevant parties while safeguarding individuals' privacy in all of these data procedures. The assessment scheme provided by Helminger and Rechberger

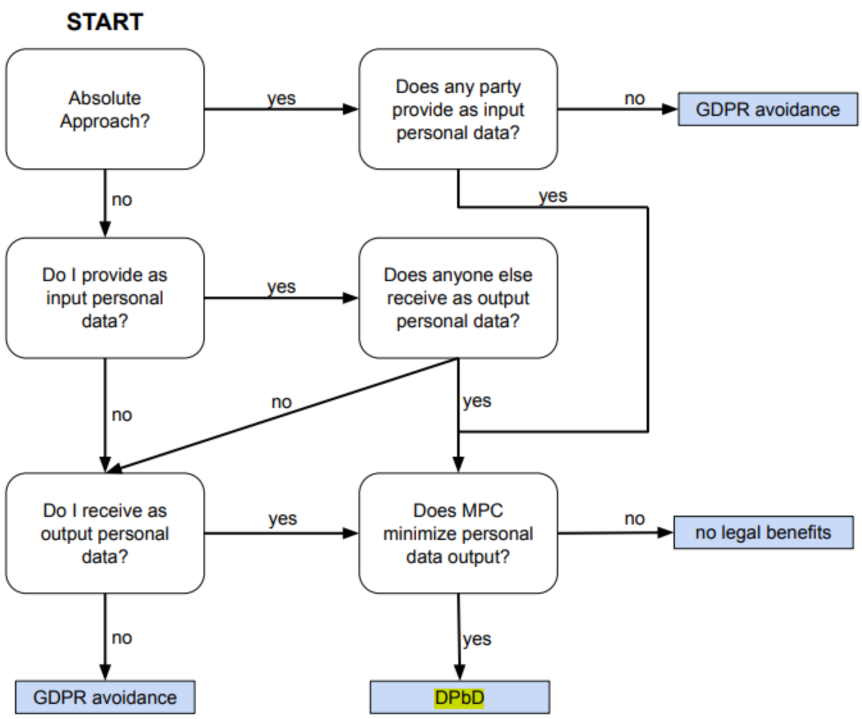

Figure 6.4: Assessment scheme for MPC in the GDPR (Helminger & Rechberger, 2022)

(2022) explains the suggestion for MPC, which is displayed in Figure 6.4. Helminger and Rechberger (2022) argues that MPC can facilitate data protection by design (DPbD), which describes integrating privacy objectives into the early design. However, the various available MPC protocols must be assessed for their applicability to ensure GDPR-compliant privacy by design. To facilitate an understanding of the scheme, it is important to notice that various stakeholders input personal data into the system. In addition, the resulting carbon credits from project subjects and the financial reimbursement households must receive are also personal data. The first decision gate described by Helminger and Rechberger (2022) refers to the chosen approach. What is referred to as the absolute approach is also the most in line with the requirements and principles determining the design. It refers to the idea that personal data is perspective-independent. In simpler terms, if one stakeholder inputs personal data, it has to be considered personal data by all other stakeholders. These two main criteria for the assessment scheme lead to the final question of the assessment, which concerns personal data minimisation. The assessment scheme's purpose for this research serves as a guideline for developing a data processing procedure using MPC protocols. However, future developers are expected to assess the protocol against the proposed scheme to ensure the data protection of individuals while not restricting data-driven business opportunities such as the desired data analysis requirements RF1.2, RF3.1 and RF4.1.

Data storage The processing of data also requires the data to be collected and stored. Information systems are based on the handling of data. However, traditional databases have reached their limits in protecting and storing data, concerning an additional need for trusted data storage (Li et al., 2018). As described by Kreibich and Hermwille (2021), the voluntary carbon credit market is facing criticisms and has to reclaim its integrity. Hence, trust is a critical challenge in today's voluntary carbon credit market (Richardson & Xu, 2020). To tackle the issue of lacking trust in the carbon credit market, various authors have suggested the use of distributed ledger technology (Richardson & Xu, 2020)(Patel et al., 2020)(Saraji & Borowczak, 2021). Several authors assessed the applicability of using DLTs, but empirical evidence for the applicability in the voluntary carbon credit market (Woo et al., 2021)(Bao et al., 2020). However, chapter 3 clearly shows the involvement of a trusted entity for the verification and certification of carbon credits, namely, the standardisation body that operates the carbon registry and the related verification bodies ensuring adherence to the standardisation body-provided standards. Research has shown that for this project as a standardisation body assigned entity, the "Gold Standard" provides robust and credible methodologies (Kreibich & Hermwille, 2021). Nevertheless, recent initiatives from the stakeholders mentioned above towards information systems based on distributed ledger technologies and academia point out the benefits of that. This led to considering distributed ledger technology for the data handling system, specifically data storage. Blockchain, or what is also referred to as distributed ledger technology, is primarily designed for the secure and transparent storing of data. The system saves data by organising it into a sequence of blocks, with each block holding a collection of transactions or information items. The blocks in question are interconnected sequentially, creating an unchangeable series wherein recorded data is rendered highly resistant to modification or deletion (Richardson & Xu, 2020). The blockchain's data security is ensured through using cryptographic algorithms, which safeguard against unauthorised access and tampering (Saraji & Borowczak, 2021). The storage of data on the blockchain is distributed throughout a network of nodes, mitigating the potential vulnerability of a singular point of failure and augmenting the accessibility of data. Transparency is a fundamental characteristic of public blockchains, as it allows for the open accessibility and verification of data by any individual, guaranteeing trustworthiness and the capacity to conduct audits. Relating that to the FCF case, which requires explicitly a transparent display of financial flows (RF1.4), distributed ledger technology seems like a promising fit. In addition, auditing procedures by verification bodies might be eased or rendered irrelevant, which could also lead to an overall effort and cost reduction in the process (Patel et al., 2020). Public blockchains are characterised by openness and lack of permission requirements, allowing anybody to participate in the network. These networks distribute data storage throughout a global network of nodes, ensuring decentralisation. These networks allow for universal participation, transaction validation, and access to the complete ledger, ensuring transparency and security via consensus methods.

In contrast, private blockchains are characterised by their confinement to a particular group or organisation, providing a more centralised form of control over data storage accessible only to a restricted range of authorised users. Implementing this mechanism enhances the efficiency and scalability of private blockchains in targeted scenarios but at the expense of reduced decentralisation and transparency compared to their public equivalents. Public blockchains place a higher emphasis on facilitating widespread accessibility and fostering worldwide trust (Lai & Chuen, 2018). In contrast, private blockchains prioritise restricted access and customised data management designed for a particular user. Kim and Huh (2020) proposes a consortium-based blockchain architecture for trading carbon credits. Consortium-based blockchains are a fusion of public and private blockchains commonly employed by a collective of reputable organisations with mutual interests (Ølnes et al., 2017). Within these networks, a predetermined group of entities controls and regulates access rights, combining the advantages of decentralisation with permission-based access (Dib et al., 2018). Consortium members actively engage in the validation process. At the same time, the transactions are duly documented in a mutually accessible ledger, thereby using the inherent transparency and security features offered by blockchain technology. Blockchains have proven to be highly advantageous when several entities must cooperate while simultaneously upholding a specific authority and confidentiality over their collective data (Gai et al., 2019). The multi-actor context of the FCF case and the need for data confidentiality make distributed ledger technology a promising approach.

Combined technologies Data processing and storage are two functional system elements allocated to the logical system element ”data handling system”. The architecture definition for these functions is a multi-party computing data processing protocol according to the suggested assessment framework by Helminger and Rechberger (2022). For the data storage functionality, distributed ledger technology has been discussed. However, it has been highlighted that in the current process of carbon credit issuance in sustainable finance projects, a central trusted authority oversees and certifies the process. Nevertheless, a consortium-based distributed ledger technology can complement and enhance trust in the system and might even be able to replace the trusted entity fully.
Data processing and data storage are two interrelated functions of the system, connected via a functional interface as seen in Figure 5.3. This requires the proposed architectural definitions, namely MPC and distributed-ledger technology, to interplay. Zhong et al. (2020) introduces the term secure multi-party computation (SMPC) in contrast to the so far introduced multi-party computation (MPC), however, referring to the same concept as discussed in this research. The publication by Jiang et al. (2022) proves that a combinable system architecture, including MPC and distributed ledger technology, is feasible and enables stakeholder privacy while not hindering multi-party computation, hence, data processing.

Interfaces The system must contain Interfaces, as displayed in Figure 5.4. There are at least five interfaces defined so far for the data handling system element. These interfaces might be what is known as application programming interfaces (APIs), which is another name for system-to-system interfaces (Uddin & Robillard, 2015). The various stakeholders utilise one or more internal information systems whenever they interact with the system. Tools for enterprise resource planning (ERP) and customer relationship management (CRM) are the typical kinds of systems that are utilised in the process (Lamothe et al., 2021). In order to ensure the scalability of the system, it is necessary to incorporate not only other projects but also possibly other stakeholders and to connect it to a variety of information systems. According to research, the number of businesses that rely on information systems and, as a result, API usage is growing rapidly (Malaurent & Karanasios, 2020). However, such systems are not the only reason to introduce APIs. Often, stakeholders' systems are more generic, like Microsoft Excel and similar tools. In the ideal scenario, all these diverse systems and applications being used are connected through APIs. During this project's stakeholder study, it was determined that the many stakeholders who interacted with the system used two distinct information system types. Two customer relationship management (CRM) systems, which are owned by the purchasing parties (interview purchasing party) and by the fuel provider (interview fuel provider), and one ERP system owned by the project developer (interview project developer). In addition to the required application programming interfaces (APIs) for information systems and applications, there must also be a human interface for those stakeholders who are not connected through system-to-system interfaces or need an additional human interface for non-automated data transfer. For example, households are not expected to use any information system or application. A human interface is required since they need to control their data within the system.

Hardware interface As discussed earlier, the data handling system comprises five different interfaces. One of these interfaces, precisely the one between function F1 and the cookstove, has yet to be detailed. This is because there has yet to be a conclusive choice taken regarding how the information system gets the data from the hob. In earlier data collection pilots involving cookstoves, the data was obtained from the cookstoves with the assistance of people who read out the data from the cookstoves and then entered it by hand into the information system (Interview project developer). On the other hand, it is envisioned that the system will automatically read the data from the range hood using either the mobile network or some other method. However, this has not yet been decided, and as a result, it is a black box interface to the system.

Alternative design

The mapping of logical and functional system elements to the suggested architectural design definition serves the latter verification of requirements against the chosen architecture. The previously mentioned discussion and decision on whether a traditional architecture or a more innovative architecture should be chosen are compared in the following two paragraphs by explaining which of the architectures would tackle which functionality. The term trust in the following refers to the underlying purpose of these architectures, which is to ensure the trust of stakeholders in the ”data handling system” with a specific focus on the six principles given by the GDPR subsection 4.2.8.

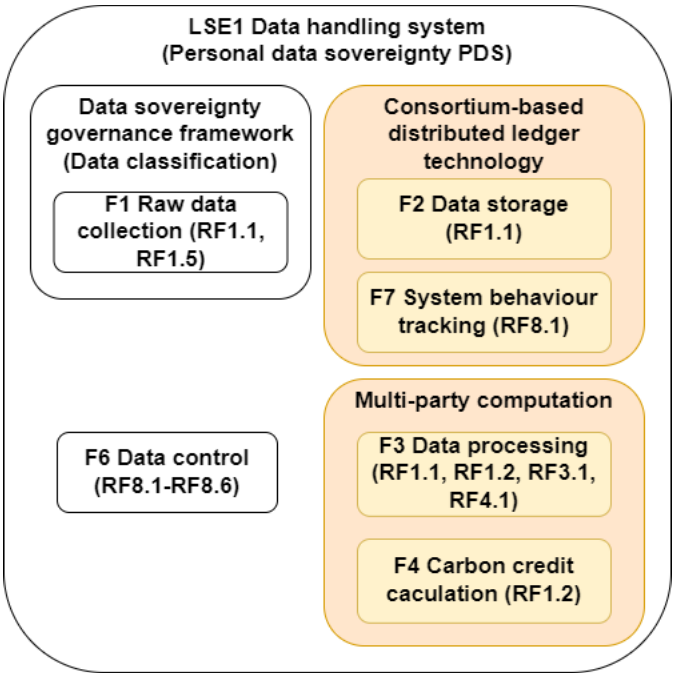

Figure 6.5: Logical and functional design definition mapping in case of a decentralized architecture

Technology-based trust and control Figure 6.5 shows the logical system element LSE1 including its assigned functionality. The architecture choices for the logical system element are mapped to the functions the logical system element is composed of. For F1, which focuses on the data input of data into the system, the data sovereignty governance framework, specifically the suggested data classification, is applicable. For the data storage (F2) and system behaviour tracking (F7), hence, data collection on system and stakeholder transactions, consortium-based distributed ledger architecture is proposed. Data processing (F3) and carbon credit calculation (F4) use MPC protocols to fulfil their tasks in line with design principles and requirements. The function data control (F6) pertains to implementing data governance measures on the platform. The data sovereignty governance framework selects the PDS principles while also using GDPR principles and local regulations to regulate the platform's data governance, as governance impacts all functions.

Central entity trust and control The visualisation of the utilisation of a conventional design for data processing systems is depicted in Figure 6.6. The dissimilarities pertaining to the decentralised architecture depicted in Figure 6.5 involve the functions labelled F2, F7, F3, and F4. The implementation of a centralised data handling system involves the utilisation of a central database that is under the control of a single institution. Utilising a centralised database under the control of a single body renders multi-party computing methods obsolete. Hence, the use of the central entity's infrastructure is employed for the purposes of data processing (F3) and carbon credit calculation (F4). The remaining two functions of the "data handling system," namely the collecting of raw data (F1) and data control (F6), experience relatively fewer significant modifications when assigned to a centralised organisation. The execution of data control (F6) by a central body can align with the concepts proposed by the PDS governance

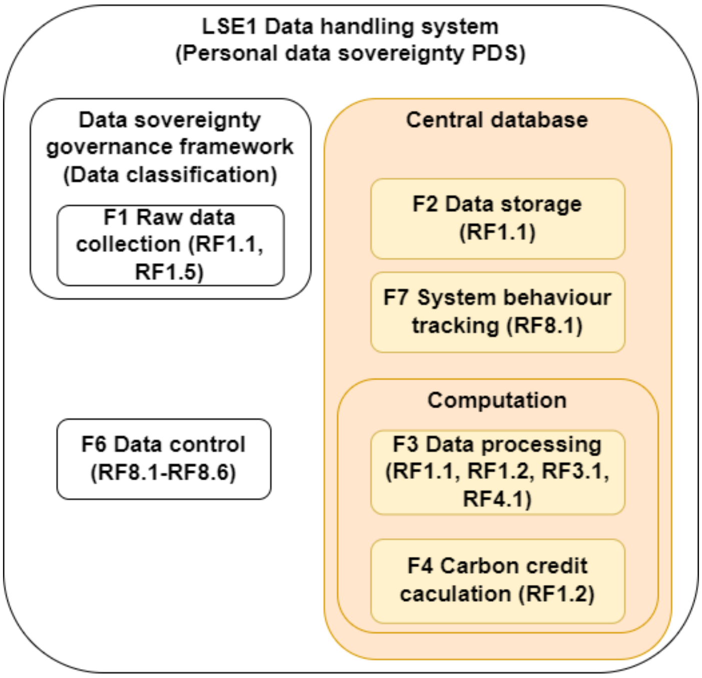

Figure 6.6: Logical and functional design definition mapping in case of a central architecture

model as outlined by Micheli et al. (2020). Furthermore, it is recommended to implement the data classification model proposed by Singi et al. (2020) to assure compliance in the collection, storage, and processing of data.

Alternative decision guidance framework This section introduces a step-by-step decision framework to guide the decision towards a centralised or decentralised architecture of the data handling system. In addition, the benefits and drawback of each of the architecutres are mentioned. The differences are visualised in Figure 6.7. The utilisation of a centralised

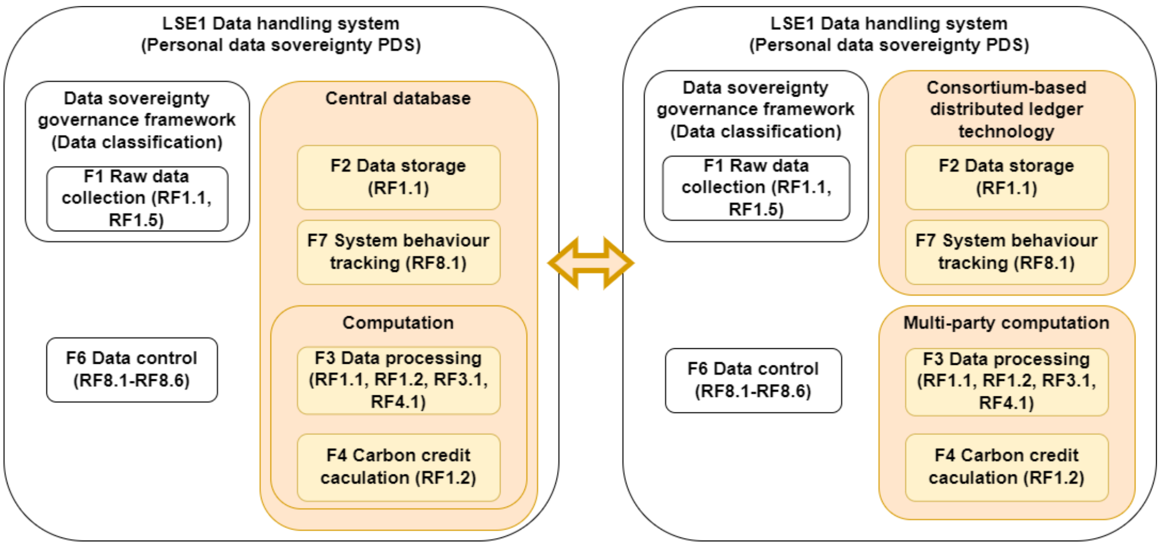

Figure 6.7: Comparism central and decentral data handling system

entity to control, store, and process data inside a multi-actor information system presents numerous notable benefits when compared to distributed ledger technology and multi-party computation. To begin with, the implementation of a clear accountability framework streamlines governance and regulatory compliance, particularly in businesses that have rigorous legal obligations (Peck, 2017). Furthermore, the process of centralisation frequently leads to improved efficiency and scalability, as it allows for the optimisation and more effective use of resources. This, in turn, leads to faster data processing and lower operational expenses. In addition, it can potentially cultivate trust among participants by simplifying the verification process, hence diminishing the necessity for intricate consensus methods (Chowdhury et al., 2018). As Chowdhury et al. (2018) defines, blockchain technology is a specific purpose technology whose usage focuses on use cases in which administration is split between multiple stakeholders who lack trust in each other. In this specific use case, the author of this research extends the definition to incorporate trust between all stakeholders and not only those with administrative power. Extending the definition serves for sustainable finance projects to all stakeholders roots in recent academic publications questioning the credibility of the overarching concept of carbon credit issuance in the voluntary carbon credit market (Kreibich & Hermwille, 2021). The general need to reacquire trust, therefore, extends to all stakeholders of the system. It is noteworthy to highlight again that design definition is a step to enhance logical system elements with additional information. Even though at this stage, the aim of the systems engineer is to define the system as solution-neutral as possible, it is agreed that partial decisions for the design have to be made and guidance for decisions has to be given (Angelov, 2023). Contextual analysis in chapter 3 describes that the current process of carbon credit issuance uses a trusted entity, while literature, as explained in this section, suggests technological means to substitute these entities. A framework by Chowdhury et al. (2018) aims at guiding practitioners with decision-making if a central or decentral approach to information system architecture should be used. The framework depicted in Figure 6.8 offers a series

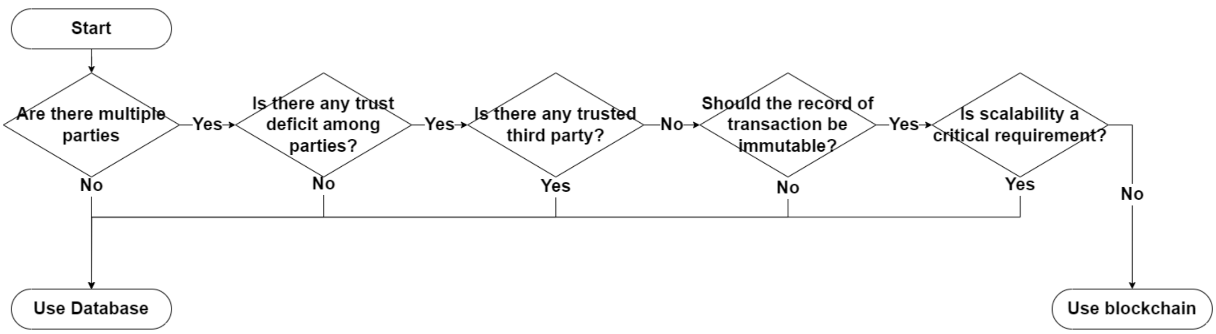

Figure 6.8: Decision tree to determine the use of blockchain (adapted) (Chowdhury et al., 2018)

of decision gates that can be responded to with either affirmative or negative answers, in order to determine the appropriateness of employing a centralised database or decentralised database, hence, blockchain technology. The author provides responses to these inquiries and emphasises the areas where judgements need to be made in order to facilitate the selection of architecture. The involvement of numerous parties in the provision, storage, and processing of data is evident, thereby satisfying the initial requirement for the rationale behind adopting a blockchain architecture. The necessity to validate carbon credit claims (RNF1.7) underscores the requirement for the record of transactions to remain unalterable. Hence, ensuring the precision and reliability of data is of utmost importance. Moreover, scholarly research conducted by Betz et al. (2022) and Kreibich and Hermwille (2021) has demonstrated that a deficiency in trust intrinsically characterises the system. Nevertheless, the framework also proposes that the utilisation of a trusted intermediary provides justification for opting for a database over distributed ledger technology. The present planned interactions among stakeholders involve the inclusion of a trusted entity responsible for certifying carbon credit claims. This prompts an inquiry into the rationale behind the examination of blockchain technology for the design of the system. Given that scalability is an essential requirement for the system, the framework suggests the utilisation of a centralised database. The framework, however, primarily concentrates on a broad methodology and neglects to recognise the advantages that result from transitioning away from reliance on a trusted intermediary. Additionally, it does not provide further clarification on the specific constraints of a scalable blockchain solution. This study suggests conducting a more comprehensive analysis of both proposed solutions. Evaluating the advantages of employing a reliable intermediary as opposed to utilising trust-enhancing technologies, and examining the market perception of these solutions, falls outside the purview of this research study. In order to address the inquiry, the scholarly publication authored by Peck (2017) might also be employed for assistance.

6.2.2. LSE2 Communication system

The second element of the logical system is referred to as LSE2, which pertains to the communication system. As mentioned earlier, the system element encompasses solely stakeholder communication (RF6.1). The communication system is derived from RF6.1, which pertains to the requirement for project subject and verification bodies to possess the capability to engage in communication. The criterion is drawn from a document outlining remote auditing processes as specified by the representative standardisation body for the system. The examination of the context and subsequent desk research has brought to light the issue of technical availability in Rwanda (Interview I4, section C.5) (Björkegren & Karaca, 2022). The system's functionality necessitates considering audibility in relation to communication. Therefore, communication may necessitate the use of visual communication to confirm the contextual conditions that are necessary for the auditing process. Various international operational companies offer Well-established audio-visual communication channels, which are used for communication between fuel providers and project subjects, for example (Interview fuel provider). This connection is established through the use of cell phones with audio-visual capability. When the technical infrastructure does not permit the establishment of a direct con-

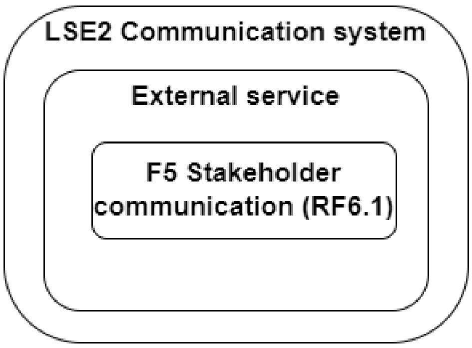

Figure 6.9: Communication system design definition

nection, it is recommended that local businesses, such as the fuel provider, assume the role of an intermediary. Intermediaries or cell phones using established audio-visual communication channels must significantly influence the information system architecture to define it further. Systems engineering refers to the external execution of a function through another system as an enabling system (Walden et al., 2015). The execution of the stakeholder communication function (F5) is, therefore, via an enabling system outside the design scope of the information system under design. To summarise, the communication system, a subsystem within the proposed information system, can be reasonably overlooked in the system's architectural design. This is attributed to the widespread availability of external communication platforms like Microsoft Teams, which offer robust and well-established communication capabilities. Nevertheless, the significance of developing interfaces to connect with these external systems seamlessly cannot be overstated. These interfaces serve as crucial connectors, ensuring that the proposed information system can efficiently and effectively interact with external communication tools, allowing for a harmonious integration of communication capabilities.

6.2.3. LSE3 Payment system

Establishing a platform payment system in Rwanda poses a complex problem, particularly in ensuring accessibility for individuals (Interview fuel provider). The digital environment of the nation exhibits notable differences in smartphone ownership and internet connectivity, particularly in rural regions. These differences can pose significant obstacles for a substantial public segment in effectively participating in online payment platforms. Nevertheless, USSD (Unstructured Supplementary Service Data) mobile payment systems are crucial in addressing these difficulties (Carr, 2007). In contrast to conventional mobile applications or online platforms, USSD services operate independently of smartphones or high-speed internet connectivity. The intrinsic accessibility of USSD makes it a compelling choice since it enables a wider range of Rwandans to engage in the digital economy. In addition, the accessibility of data plans and smartphone devices may present economic obstacles to participation, particularly for persons with little financial resources, which is often the context in sustainable finance projects. USSD services are characterised by low data consumption, rendering them a financially efficient option for individuals with restricted means. Moreover, these services can be readily accessed using commonly available and generally recognised basic mobile phones, which are familiar to a significant portion of the Rwandan population (Interview fuel provider)(Uwamariya & Loebbecke, 2020). Frequently, USSD services are supported by reputable mobile network operators, which possess a considerable degree of trust among consumers who have historically depended on their services for fundamental communication requirements. In the context

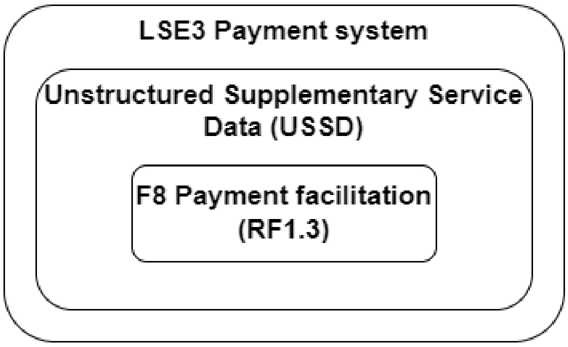

Figure 6.10: Payment system design definition

of the FCF example, the difficulties surrounding facilitating connections between individuals in Rwanda and platform payment systems are acknowledged. However, it is worth noting that USSD mobile payment services are crucial in effectively tackling these obstacles. The inclusive nature of these solutions, along with their accessibility, affordability, and compatibility with current mobile infrastructure, make them well-suited for enabling a broader range of individuals to engage in the digital financial ecosystem. This includes individuals who have limited access to smartphones and the internet. Nevertheless, despite the significant advantages of USSD services, scholars like Lakshmi et al. (2017) have documented several security concerns and risks associated with these services. Hence, it is crucial to thoroughly assess the selected USSD service provider under the principles and requirements of the designed system, which pertain to the abovementioned concerns. To conclude, the payment system, a subsystem within the proposed information system, does not necessitate dedicated design by information system developers. In Rwanda, an existing system known as USSD already fulfils this function effectively. Rather, the focus should be on integrating the information system with these ”enabling systems” and establishing robust interfaces for seamless connectivity. This approach ensures the preservation of valuable functionality while maintaining compatibility with established systems, minimizing redundancy, and streamlining the information system’s capabilities.

6.2.4. LSE4 Visualization system

The data visualisation system focuses on a stakeholder-centric perspective regarding impact visualisation (F9), acknowledging that diverse stakeholders, such as purchasing parties, may possess different demands for impact visualisation (Interview purchasing parties). It is acknowledged that the interpretation and portrayal of data can exhibit significant variation, contingent upon stakeholders’ objectives. The primary focus of this system is to prioritise the provision of anonymity data, along with the design principles and needs of the system. By implementing this approach, the confidentiality and protection of sensitive data are guaranteed while simultaneously granting stakeholders the flexibility to customise the visualisation of outcomes according to their unique circumstances and goals. However, the functionalities ensuring these principles are part of the logical system element LSE1. It is contentious that granting stakeholders the authority to select the manner in which data is presented facilitates variations in the representatives of purchasing parties and between projects. The platform under design facilitates the creation of visualisations by providing users with an interface. This allows them to generate visual representations that are both relevant and actionable according to their needs, thereby aligning with their specific goals. The versatility and efficacy of only providing anonymised data and incorporating user-driven impact visualisation. This allows for catering to the different requirements of stakeholders. The provision of an interface to stakeholders is discussed in the previous section. The stakeholder project developer necessitates the inclusion of function F10 to promote transparency within the overarching sustainable finance project, specifically concerning the visualisation of financial flows. The interface (API) is utilised to supply the pertinent anatomised data in alignment with design principles and system requirements. This data is then integrated with the project developer's website, per their request (Interview project developer). Similar to LSE2, the communication system and its functionality, the visualisation functionality is executed via an enabling system, and only the provision of relevant data via an interface is within the design scope (Walden et al., 2015). In simpler terms, this means that the visualisation system, operating as a subsystem within the proposed information system, is not in the direct focus of architectural design. Instead, the primary focus should be directed towards delivering the requisite data and interfaces. By doing so, users who seek to visualize data are empowered to employ their preferred visualization tools and platforms, catering to individual preferences and specific visualization needs. This approach maximizes flexibility and user autonomy, offering a tailored and efficient approach to data presentation while obviating the need for an intricate, dedicated visualization subsystem.

6.3. Key findings

It is noteworthy but not surprising that the most emphasis in the architectural and design definition process lies on the data handling system (LSE1). The chapter elucidates the correlation between architectural selections and the comprehensive procedure of carbon credit issuing while addressing the study inquiry: "Which architectural designs can effectively accommodate the specified requirements?". In conclusion, this chapter of design definition explores the architectural choices relevant to the four fundamental logical system components: the "data handling system," the "communication system," the "payment system," and the "visualisation system." The "data handling system" receives significant attention and importance due to the extensive set of requirements it imposes, particularly those mandated by GDPR compliance. This particular component functions as the fundamental basis of our information system, symbolising the necessary commitment to the principles of data security, preservation of privacy, and responsible data management. For the "data handling system", two alternatives regarding the architectural choices are provided. The chapter additionally provides a framework to guide the decision process for architectural choices regarding the "data handling system". No clear tendency towards choosing one of the alternatives could be identified by the author, mainly by the fact that a decision for an alternative can only be made after a thorough analysis. Both alternatives provide the functionalities required to achieve the overall goal of the system. However, other non-technical factors are expected to influence the usability of different alternatives. An example is that the different alternatives must be accepted by other stakeholders interacting with the subsystem, and public acceptance of technology-based trust mechanisms is also concerning to the author. Public acceptance might influence the perceived credibility of the subsystem and therefore might impact carbon credit sales. In contrast, the "communication system" and the "visualisation system" are categorised as enabling systems intended to be provided externally by third-party entities or corporate enterprises. This strategic imperative allows for aligning our fundamental capabilities with our primary objective while leveraging external expertise to coordinate communication methods and data presentation. However, the concept of the "payment system" presents a unique challenge, specifically in the context of Rwanda. Incorporating local resources, particularly the USSD service, is a necessity arising

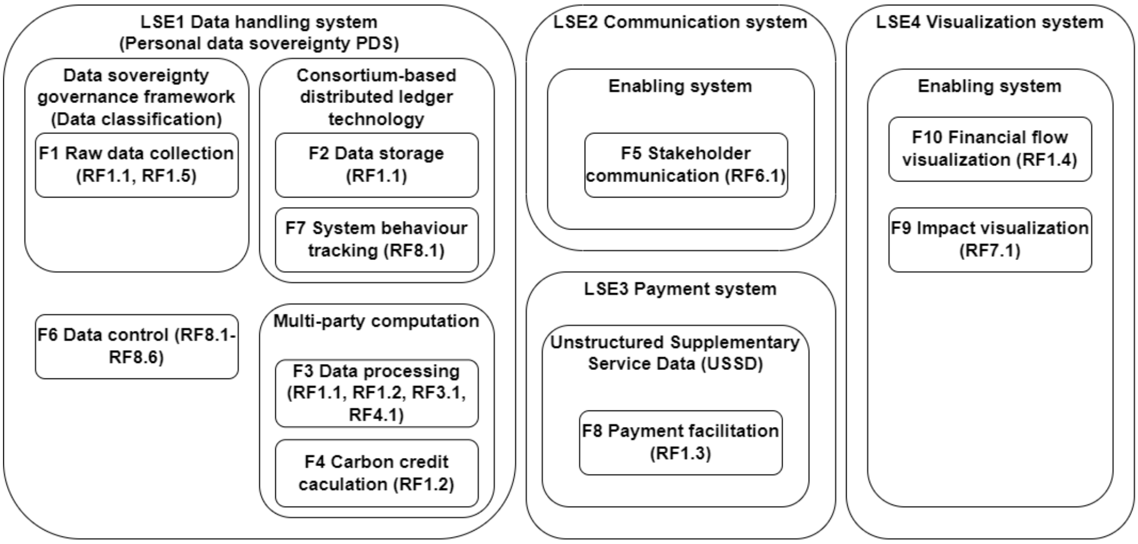

Figure 6.11: Overview Logical System design definition for distributed architecture

from the determined need to connect all project subjects to the payment system. Despite including an inherent element of risk when using USSD services, it is the most promising solution. The design paradigm we employ involves carefully balancing priorities and interdependencies. This is supported by a strong commitment to maintaining data integrity, ensuring robust security measures, and aligning with existing regulatory frameworks. The comprehensive design configuration presented Figure 6.11 serves as an overview of system architecture and design definition. One notable finding is the identification of an architectural alternative that allows for the removal of the trusted party in the carbon credit issuance process. Based on the findings of the context analysis, it has been determined that the involvement of trusted entities in sustainable finance initiatives contributes to the lengthy duration of carbon credit issuance. The potential of technological solutions to replace these parties holds promise in expediting the process of issuing carbon credits while upholding established standards and ensuring compliance.

7

System Evaluation

The responsibility of assuring the dependability and functionality of complex socio-technical systems is of utmost importance in their development (Holt et al., 2015). This chapter focuses on system evaluation, which is a critical element in the process of system deployment and utilisation and aims at answering the sub-research question:" How well do the proposed architectures fulfil the specified requirements?". The evaluation step and the previous steps are displayed in Figure 7.1. This research focuses on two interconnected ideas crucial in evaluating systems: verification and validation (Walden et al., 2015). Verification refers to the systematic procedure of checking the accuracy and correctness of a system's development, ensuring that it aligns with its predetermined requirements and planned functionalities (Holt et al., 2015). The primary objective is to assess the extent to which the system fulfils its pre-established requirements. Verification, at its core, aims to address the fundamental inquiry, if the system is built correctly. This phase facilitates the identification and resolution of conflicts or faults that may have arisen throughout the design and development phases, so guaranteeing that the system remains consistent with the initial vision. In contrast, the validation process is centred around assessing the extent to which the system effectively achieves its intended objectives within the practical context of real-world usage. The primary objective of this inquiry is to address the fundamental query if the system fulfils its purpose (Holt et al., 2015). Validation is a critical process that ensures the system adheres to its specified requirements and effectively fulfils its users' authentic needs and expectations. This phase frequently includes user testing, real-world situations, and performance evaluations to verify that the system functions as intended and provides the anticipated value. However, since the system is still in a conceptual state, the above-mentioned approaches are not suitable. For this reason, expert interviews are conducted which represent stakeholder groups. Verification and validation are two crucial components of system evaluation, playing a pivotal role in assessing a system's quality, reliability, and functioning prior to its deployment. The system evaluation process employs two separate approaches to address the inquiries offered by verification and validation. Initially, a thorough examination is conducted on the stipulations outlined in chap-

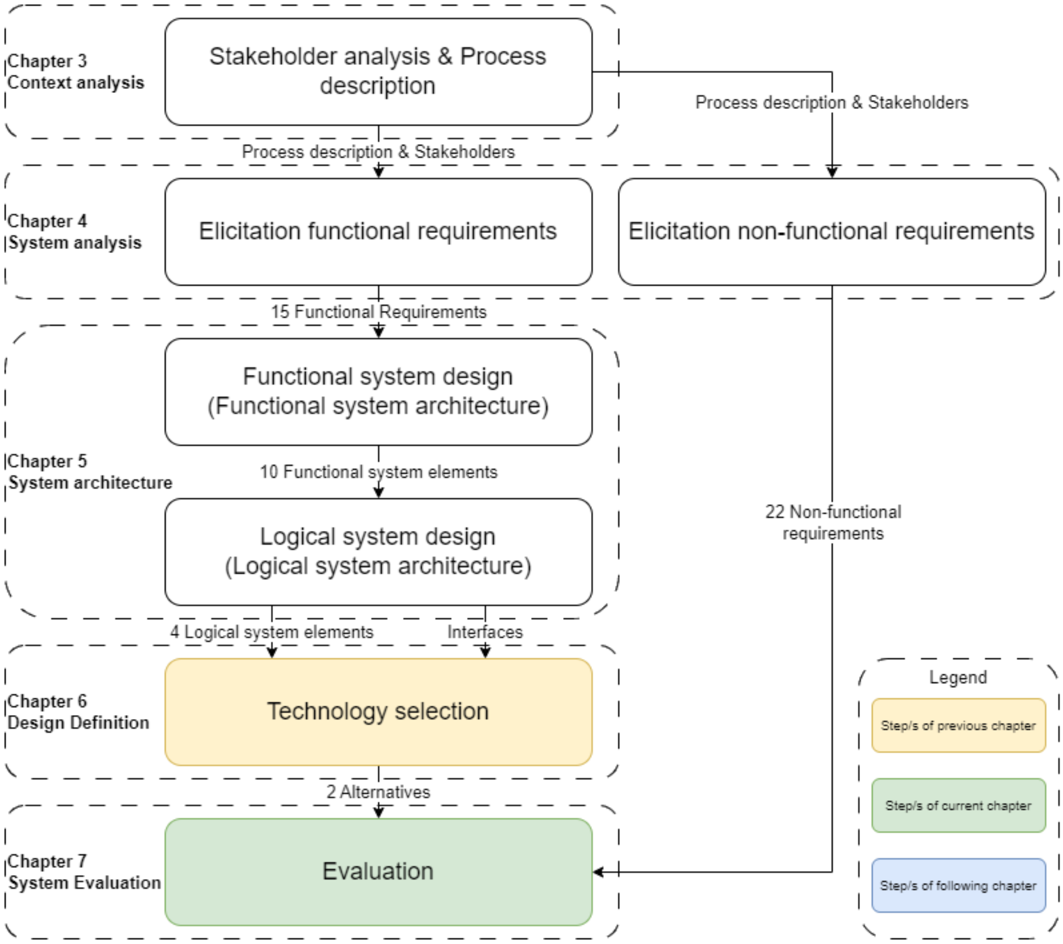

Figure 7.1: Process model

ter 4 and subsequently correlated with the functionalities and logical constituents delineated in chapter 5. The system architecture needs to be designed to effectively cater to the initial identified requirements, hence meeting the needs of the stakeholders. The matrix depicted in the Table C.3 illustrates the correlation between criteria and the entities stated above. The second approach seeks to ascertain whether the system effectively achieves its intended objective. As delineated in chapter 1, this study's system architecture and intermediate findings are intended to guide project developers and act as input for information system developers in their respective processes. Hence, the consultation of a specialised system engineer with expertise in information systems is sought to assess the design and intermediate outcomes in terms of their utility to the developers. Furthermore, an interview is conducted with a project developer to assess the efficacy of the aforementioned deliverables from their standpoint. Both interviews follow the same structure, sequentially discussing each main deliverable of the research cycle steps. The interviewees comment on their usability and readiness for a handover to project or information system developers.

7.1. System verification

As previously mentioned, the author mapped the initial requirements onto functions and system elements in Table C.3. Two categories are introduced, in green, the category for requirements which are determined to be considered by the architecture. The other category, orange, indicates that the architecture does not consider requirements or cannot be verified at this stage. Since the architecture is in a conceptual stage, and certain requirements focus on more detailed aspects, these requirements must be verified later. The following paragraphs explain all requirements classified as orange. The author opted not to elaborate on the fulfilled requirements because it is anticipated that the mapping onto functions in the verification matrix would make it self-explanatory. In other words, the matrix should clearly indicate which requirements have been met by the introduced functions, making additional explanations redundant.

The system must facilitate scalability to encompass all future projects. The scalability requirement cannot be verified at this stage due to pending decisions for the architecture. As described, the centralised architecture performs better in regard to scalability when compared to the decentralised alternative. However, also centralised architectures vary in scalability; therefore, the requirement has to be verified at a later stage.

The system must facilitate the certification process for carbon credits, adhering to standards such as Gold Standard and Fair Trade Climate Standard. The need to receive certification from the Gold Standard and Fair Trade Climate Fund is undoubtedly critical. Both organisations provide very elaborate documentation on the certification of clean cooking projects. However, neither of the organisations provides guidelines or requirements for interacting with an information system such as the one proposed by this research. It is suggested that the system architecture be reviewed and discussed with the above-mentioned stakeholders.

The system must be designed to be user-friendly and self-explanatory for easy access by project participants. & The system must be easy to use and understand for users of all reasonable ages and levels of education. The user-friendliness is mainly determined by the user interface. The need for an interface is discussed in chapter 5. However, it is not detailed enough to evaluate if the requirement is fulfilled.

The system must connect with CRM and ERP systems of stakeholders. Similarly to the previous requirement, stakeholders' connectivity with CRM and ERP systems can not yet be verified. This is influenced by the conceptual stage of the system but also by the lack of knowledge of final stakeholders in the system.

The system must be affordable for low income households. To determine the cost of the system, it needs to be further specified and leave the conceptual stage. In addition, the requirement specifies that the system must be affordable for households and does not specify costs for other stakeholders. At the stage of the research it is not clear how the costs will be distributed per stakeholder. Literature also defines the term affordable in the context of clean cooking projects as variable (Gill-Wiehl et al., 2021).

The system must establish security measures to ensure the integrity, and confidentiality of processed personal data while not storing data longer than necessary or needed for the defined purpose. Despite being a critical requirement, as previously explained, the conceptual stage of the system and the lack of detailed design, prohibits this requirement from being verified at this stage.

The system must ensure that individuals are not subject to automated decisions without human intervention and must allow them to contest such decisions. The system architecture currently does not incorporate the function of automatic decision-making. Nevertheless, data analysis functionalities are requested and incorporated into the system's functional architecture. How the outcomes are used cannot be determined now; therefore, the requirement must be verified later.

Institutional requirements The following requirements cannot be verified due to two factors. The first is that legal expertise is necessary for a legal assessment, necessitating a greater processing time than this project allowed. Therefore, further study on this is necessary. The legal documents provided by the institutions were reviewed. However, compliance can not be assured. The second factor is that the current development stage of the system does not allow for a complete verification against legal documents resulting from the conceptual stage it is currently in.

- The system must be compliant with the Directive 2009/136/EC.
- The system must be compliant with the Data Act -Proposal.
- The system must be compliant with the Data Governance Act.
- The system must be compliant with the Communication Technologies Law No. 24/2016.
- The system must be compliant with the ePrivacy Directive (2002/58/EC).
- The system must be in line with customs, religion, tradition and norms given in the region and community.

7.2. System Validation

The system validation makes use of expert interviews. One interview was conducted in collaboration with a company actively developing clean cooking projects. This approach has been undertaken to capture the practical insights and perspectives of experienced practitioners working in the field. Furthermore, the second interview within this protocol has been conducted with an experienced systems architect specialising in information system design. This interview aims to provide valuable insights from an individual with the expertise to evaluate the readiness of the deliverables for further development. Combining these perspectives ensures a comprehensive assessment of the various facets of the design cycle, ultimately contributing to its validation and refinement.

7.2.1. Evaluation: Systems Engineer

Overall, the system engineer described the system architecture and intermediary results as a fundamental step enabling developers to understand what the system needs to do and in what context it has to be placed in. However, before the system is deployed, it was suggested that all design steps be reviewed and further detailed to ensure a successful system deployment. The key aspects to improve on discovered in the interview are mentioned below.

- The system engineer emphasised the importance of refining requirements before engaging in system design to ensure a successful deliverable when the information system is developed.
- The inclusion of a thorough cost analysis was recognised as an essential component to make well-informed judgements and maximise the efficiency of the design, underscoring the significance of considering financial limitations during the architectural process.

7.2.2. Evaluation: Project Developer

The project developer described the system architecture and the subsequent results as insightful and helpful in facilitating an understanding of project developers. Some aspects of the system architecture and the design process were described as being too ”technical”. It was also highlighted that other stakeholders should be consulted to ensure that their perspectives are represented. The key points which need to be improved are listed below.

- It is suggested that all relevant parties engage in a comprehensive evaluation of the deliverables to ascertain their efficacy from all perspectives
- There are specific components of the deliverable that are described as being too ”technical.”

7.3. Key findings

The evaluation of a system architecture holds significant importance as it is a crucial checkpoint for quality assurance- and to answer the sub-research question: ”How well do the proposed architectures fulfil the specified requirements?” (Holt et al., 2015). The utilisation of this approach enables the detection and resolution of design deficiencies and incongruities before the system's progression in the developmental phase, therefore resulting in time and resource conservation. Furthermore, the system evaluation process verifies that the architectural design is in accordance with the expected functionality and requirements, mitigating the potential for expensive difficulties that may arise after the system is deployed (Walden et al., 2015). The chapter has highlighted the need for improvement according to two approaches. Verifying functions and system elements against requirements has resulted in a list of requirements that have to be verified later for various reasons. The validation with experts has led to the insight that the architecture and intermediary results must be further developed for system deployment. However, expert interviews have also shown that the level of technical detail is not expected to be clear to every stakeholder, which conflicts with the idea of providing development guidelines for project developers of clean cooking and sustainable finance projects. The overall results of the system evaluation show that the system architecture is in coherence with the requirements which could have been verified. Despite not all requirements being verified due to the reasons explained in this chapter, there is no violation of requirements. It's important to note that while these results provide valuable insights into the system's alignment with current requirements, they should be interpreted carefully. A comprehensive verification of the system architecture can only be achieved after further development, testing, and refinement of the architecture.

8 Conclusion

This chapter concludes the research by answering the main research question. In addition, societal and academic contributions of the research are discussed. Lastly, limitations to the research and future research topics are elaborated.

8.1. Answering the main research question

This research presented a design science cycle according to Peffers et al. (2014) further detailed by using systems engineering guidelines and best practices by Walden et al. (2015) to elaborate a design of a multi-actor platform for the issuance of carbon credits. The following sub-research questions are answered and reflected on to answer the main research question.

SQ1 What is the context of the system intervention? In order to examine the existing procedure of carbon credit issuance in clean cooking initiatives, an analysis was conducted on the FCF case in Rwanda. The present investigation encompassed a comprehensive examination of the stakeholders involved. The identification of pertinent stakeholders was accomplished by utilising participatory observation techniques at the FCF and examining internal documents. Furthermore, the researcher identified relevant institutional stakeholders through comprehensive literature and documentation reviews. The carbon credit issuance process functions were then assigned to the stakeholders. Furthermore, the stakeholders, who play a significant part in the given context, were augmented by including the occupant's role in the FCF instance. The aforementioned study was subsequently employed to explicate the intricacies of the carbon credit issuance procedure, furnishing a comprehensive perspective of the entire system. The stakeholders were subsequently arranged in a grid format to represent the power dynamics among them visually. The analysis led to the identification of key stakeholders and bottlenecks within the process. The project developers, households, and verification bodies are the three primary stakeholders who exert significant influence over the many capabilities inside the process, demonstrating considerable power. The observation that a stakeholder with significant influence contributes to a slower overall process is pertinent, as it is currently deemed infeasible to replace this stakeholder. The multi-actor environment, multinational institutional actors, and intrinsic collaborative efforts pose additional obstacles.

SQ2 Which design principles and requirements define the system? In order to ascertain the requirements and design concepts pertinent to the information system, the stakeholders identified earlier were either subjected to interviews or their publicly available and internal papers were examined. In specific instances, the needs and requirements articulated by stakeholders were rephrased to function as high-level requirements for the development of the system. During the second phase, the requirements were classified into two distinct categories: functional and non-functional requirements. This classification yielded a total of 15 functional requirements and 22 non-functional requirements for the system. The non-functional criteria were categorised into six distinct groups based on their respective types.

- Scalability (1 requirement)
- Compliance (9 requirements)
- Performance (2 requirements)
- Usability (2 requirements)
- Process (7 requirements)
- Interface (2 requirements)

Two distinct categories of requirements are significantly larger compared to the remaining categories, specifically the ”compliance” and ”process” requirements. Although the ”process” requirements only have a limited connection to the information system design as they mostly pertain to the deployment procedure of the system, they have not been disregarded to guarantee that all stakeholder needs are taken into account during the design phase. The subsequent collection of requirements, which was notably larger, pertained to compliance. In the subsequent phase, a comprehensive analysis was conducted on the functional requirements to ascertain their relationships with various non-functional requirements groups. Unlike functional requirements, non-functional requirements do not directly impact the system’s functionality. Instead, they shape the functions given by the system’s functional requirements. In order to identify the relationships between functional and non-functional requirements, their effects on each other were documented. The comprehensive compilation of requirements and principles addresses the sub-research question. It is important to highlight that the project developer inputs a significant proportion of functional requirements, whereas a considerable portion of non-functional requirements, particularly those pertaining to ”compliance,” are typically provided by institutions.

SQ3 Which architecture designs can facilitate the specified requirements? For the architecture design phase, the author divided the answer to the sub-research question over two chapters, chapter 4 and chapter 5. The initial chapter examines the functional requirements of the preceding sub-research question and utilises them to deduce functions for the system.

As a consequence, a total of ten functions were identified as necessary for the system to effectively fulfil its intended overall functionality. These functions are referred to as functional system elements. The functions were further examined in terms of their interrelationships. The functions and their interconnections were assigned to•logical sub-systems in the subsequent phase. The process of categorising elements into logical sub-systems is intended to identify functions with a tight relationship and can be associated with technological resources in subsequent stages. Consequently, four distinct logical subsystems emerged, with the ”data handling system” encompassing six out of the ten overall functions. The other logical subsystems, namely the ”communication system,” ”payment system,” and ”visualisation system,” encompass the remaining four functions. These findings facilitated the understanding that the ”data handling system” is the subsystem requiring the most attention since it also incorporates the functions most restricted by ”compliance” requirements. The logical system elements exhibit interconnections among themselves and with stakeholders, which engage with specific logical system parts. This stage is conducted in order to ascertain the various interfaces that are necessary. The interfaces can be classified into two categories: external interfaces and internal interfaces. The external interfaces are further delineated based on their respective utilisation: machine-to-machine interfaces and interfaces designed for human interaction.
The second chapter, chapter 5, picks up on the previous and provides more detail about the logical system elements and the system's deployment. The process requirements that were previously obtained are utilised as input to delineate the necessary steps of the process prior to system deployment, to guarantee adherence to the aforementioned requirements.
In the subsequent phase, additional elaboration is presented regarding the system's constituent elements. The data handling system garners significant attention due to its extensive and relevant functions, leading to the decision to offer two alternatives for it. The system element has been enhanced with comprehensive information pertaining to data governance, processing and storage, as well as its software and hardware interfaces. The first alternative presents a decentralised high-level architecture for the ”data handling system,” whereas the subsequent alternative outlines a centralised solution. The chapter additionally presents theoretical frameworks that can be utilised to facilitate the decision-making process on architectural choices.
The other subsystem receiving noteworthy attention in the design is the ”payment system”. This originates from the crucial need to reimburse the project subjects financially. A locally available payment service integration is discussed.
The other two systems are determined as enabler systems by the author and, therefore, are not suggested to be designed, but external solutions should be used. Ensuring the functionalities of these systems is achieved via a focus on the interfaces with them.
In summary, the sub-research question is answered by providing two different architectures and frameworks for guidance in the decision process for these.

SQ4 How well do the proposed architectures fulfil the specified requirements? The system evaluation verifies and validates the system architecture. The researcher has verified

the requirements by mapping the functions and logical system elements. The resulting matrix was then analysed for requirements which are not fulfilled by the system architecture. Overall, 14 requirements can not be verified at this stage of system development. Two main reasons are identified for the non-verified requirements. The first is the high-level architecture, which does not allow for a detailed analysis to verify requirements. In simpler terms, it means that design decisions have not been made at this stage, and more details have to be added to determine if requirements are violated or met. The second reason is the lack of resources to assess the legal documents fully. It can not be guaranteed that the various legal documents were interpreted correctly and have only been reviewed on a high level. Therefore, all requirements concerning compliance with legal documents are considered not fulfilled. The system validation, concerning its usability in practice, was conducted via the use of interviews. Two experts were tasked with answering the usefulness of the system architecture and intermediary results from two different perspectives. The expert in systems engineering reflected on the usability of the system model, hence the system architecture and all intermediary results, to information system developers. It was indicated that the system model's level of detail is insufficient to start development. All system model aspects must be further detailed but fulfil the requirements for a high-level systems model. The second expert is a project developer who reflected on the usability of the research for project developers. This perspective requires a less technical view and aims to facilitate an understanding of the system model. However, the interview led to the insight that certain aspects of the system model are indeed described as too "technical".
Overall, the proposed architecture fulfils the functionalities requested by stakeholders. Nevertheless, 14 out of 37 requirements are not verifiable at this stage of system development, which is a significant amount. The system model, however, still meets its purpose of providing guidance to the project developer.

What is a possible design for a digital multi-actor platform for the issuance of carbon credits? The study aimed to develop a multi-actor platform designed to facilitate the issue of carbon credits in clean cooking projects. To accomplish this objective, the study presents a design cycle, utilising a case study conducted in the specific setting of Rwanda. Additionally, the study proposes a system architecture and offers decision-making frameworks to guide significant decisions pertaining to the design of the system. The problem context discussed in chapter 1 serves as input to answer the question. The design was intended to improve on the existing process, with a particular emphasis on the length of the certification process, the cost of registration, presumptions regarding cookstove usage, and the lack of transparency.
All of these issues were addressed in the design that was provided in this research, which is anticipated to make a considerable improvement. The answer to the first sub-research question was that the system's verification and certification bodies are responsible for the lengthy certification procedures. An approach that would enable the exclusion of these parties and fully automate the certification process while ensuring trustworthiness through the use of innovative technologies is the decentralised system architecture given in chapter 5. If verification

and certification authorities are open to joining the proposed system, the centralised architecture is also anticipated to speed up the certification process.
As a result, the cost of registration is anticipated to decrease even though this research cannot guarantee it due to a lack of cost estimates. The technology offers a starting point for reducing the amount of human effort during the process, therefore reducing costs.
By using IoT technology to monitor the cookstove, the third point—the assumption regarding the use of the stove is addressed. The method eliminates the use of assumptions and can measure the usage.
The lack of transparency was the final significant factor in the problem scenario. The system adds a feature that can expose all system transactions to parties with access to this data while transparently tracking them all.
The author believes that because the system answers all of the initial issues and the sub-research questions, the main research question, which was formulated to address these challenges, is answered.
In summary, the comprehensive research undertaken to address the main research question and its four sub-research questions has provided valuable insights into designing a digital multi-actor platform for carbon credit issuance in the context of clean cooking projects.

SQ1 The first sub-research question revealed the complex stakeholder landscape, with certain entities holding significant power and the potential for bottlenecks in the credit registration process. This understanding is vital in designing interventions that address these dynamics effectively since it highlights the inherent complexities of such a design.

SQ2 The second sub-research question emphasised the paramount importance of regulatory compliance in carbon credit issuance and the diverse network of requirements interdependencies. This underscores the need for a comprehensive, stakeholder-inclusive strategy in system design.

SQ3 The third sub-research question culminated in a comprehensive architecture that underlines the significance of the ”data handling system” and the challenges of choosing alternatives within it. This chapter also identified the potential for technology to replace trusted parties, potentially expediting the credit issuance process.

SQ4 The fourth sub-research question engaged in system evaluation, revealing a coherent alignment of the system architecture with the requirements that could be verified. However, it is crucial to interpret these results carefully, recognising that full verification can only be accomplished after further development and refinement of the architecture.

Addressing Core Problems of Clean Cooking Projects This research has successfully addressed fundamental challenges that concern clean cooking projects. The result is an information system architecture that effectively resolves these issues and lays the foundation for a more streamlined, transparent, and impactful future for carbon credit issuance within clean cooking initiatives.

One of the primary obstacles the research addresses is the duration of the certification process. By introducing an architecture designed to optimise data management and data accessibility for diverse stakeholders, we anticipate a notable reduction in certification time. Additionally, the prospect of transitioning to technology-driven verification procedures promises swift, automated certification processes. This enhancement expedites the process and enhances the overall efficiency of the carbon credit issuance process.

The information system also addresses the second challenge, carbon credit registration costs. As the certification process becomes more efficient and automated, a corresponding reduction in associated expenses is anticipated. This cost-effectiveness improves clean cooking projects' economic viability.

The third pivotal issue, namely the assumptions regarding cookstove usage time, has been effectively resolved by introducing a monitoring device. Therefore, the information system relies on precise measurements rather than assumptions, resulting in a significantly more accurate data collection process and, by extension, more reliable carbon credit calculations.

The architecture ensures targeting the transparency issue by the seamless interconnection of data related to cookstove usage, users, emission reductions, carbon credits, and credit recipients, offering a comprehensive and transparent view of the entire process. This elevated level of transparency instils confidence among stakeholders and addresses concerns raised in recent research regarding the potential over-issuance of credits.

The research has presented a comprehensive and transformative approach to the persistent challenges confronting clean cooking projects. The architecture conceived effectively resolves these core issues and sets the stage for more environmentally responsible, efficient, and sustainable clean cooking initiatives. It contributes to collective environmental and health objectives.

8.2. Adaptability of the Designed Information System Architecture

The designed information system architecture, tailored for clean cooking projects in the specific context of Rwanda, the author assumes that it possesses a crucial quality that enables broader applicability: adaptability. While the architecture is meticulously crafted to address the intricacies of the clean cooking project in Rwanda, it is intentionally kept on an abstract level to serve as a foundation that can be flexibly adapted to different contexts and projects within the realm of carbon credit issuance. The value of the design cycle steps and the comprehensive explanations within them extends beyond the boundaries of Rwanda. Project developers engaged in clean cooking initiatives in various geographical and operational contexts can leverage the principles and methodologies outlined in this research. By doing so, they can tailor the architecture to suit their unique needs while benefiting from the structured design approach that considers functionality, compliance, and adaptability. Thus, The research serves as a valuable reference guide for practitioners looking to embark on similar endeavours, offering an exemplary system design process. Another key factor enabling the adaptability of the information system architecture is its uniformity in data collection. This characteristic is integral to the architecture, enabling it to cater to clean cooking projects and other initiatives where data collection is imperative to issuing carbon credits. The author believes that the system, due to its high level of abstraction, can also be adapted to fit a context outside of sustainable finance projects. For projects requiring a similar basic concept of collecting, storing and processing data in a way in which data is kept confidential, and the processes need to be executed compliant, the research and the produced system architecture can serve as valuable input. In essence, the level of abstraction, and therefore, its adaptable nature of the designed information system architecture, positions it as a versatile tool that transcends the confines of a single context.

8.3. Societal contribution

The system design presented in this research study exhibits considerable promise for the FairClimateFund and similar endeavours within clean-cooking and sustainable financing domains. There are numerous significant benefits associated with its implementation in these particular circumstances. The model presented in this study serves as a tool for understanding the complexities of the design process in the fields of clean cooking and sustainable financing. Presenting a model design cycle assists stakeholders in acquiring a comprehensive understanding of the structured process of creating information systems to meet similar requirements. Additionally, the model showcases a comprehensive and adaptable system design that demonstrates versatility and applicability outside its initial context. The versatility of this reference design allows for its use as a foundational reference architecture in sustainable finance initiatives. The inherent flexibility of the system architecture allows project developers and stakeholders to customise the contextual aspects to suit their own initiatives. The projected result of this endeavour is a higher adoption rate of information systems in different initiatives, which is anticipated to address the difficulties and obstacles commonly associated with projects of a similar kind. The collaborative attempt described herein plays a crucial role in tackling the issues associated with clean cooking, sustainable financing, and related initiatives, hence promoting the overall sustainability agenda.

8.4. Academic contribution

The academic literature has a deficiency in the accessibility of reference architecture and detailed guidelines specifically designed for clean cooking projects that aim to utilise information technologies in order to tackle the inherent problems and obstacles associated with their endeavours. This study aims to address this gap by providing two significant contributions:

First and foremost, it provides a carefully organised and systematic design cycle as a demonstrative example for developing information systems specifically designed to facilitate clean cooking projects. The design cycle outlined in this research functions as a pragmatic guide for stakeholders, facilitating the stages of context analysis, requirements elicitation and system architecture design of information systems that are specifically developed to meet the distinct requirements of clean cooking initiatives.

Additionally, this study presents a reference architecture that is designed to function as a basic structure. The provided reference architecture holds the potential to benefit researchers and practitioners in the field of information systems who aim to expand its utilisation in sustainable finance projects. By providing this reference architecture, the research aims to build an initial foundation to facilitate a more comprehensive investigation into the deployment of information systems in sustainable finance.

The aforementioned contributions aim to address a deficiency in the academic domain. They offer practical advice for clean cooking initiatives and establish a strong basis for extending information systems in the wider field of sustainable financing. Through these endeavours, our aim is to facilitate the development of novel solutions, foster more research, and promote the collaborative goal of sustainability within these areas.

8.5. Limitations

Various limitations have substantially influenced the approach and consequences of this academic research, operating within its defined scope. It is imperative to recognise and accept the significance of these restrictions, which include data sources, stakeholder participation, legal restraints, and the author's competence in the legal domain.

The utilisation of data obtained from private enterprises gives rise to an inherent constraint. The potential for bias in the available data may increase, impeding our capacity to obtain thorough insights. A comprehensive approach involving meticulous data validation and cross-referencing techniques has been implemented to address this issue. A second aspect is the relatively low number of stakeholder interviews and the lack of verification cycles with stakeholders after every intermediary design step. Enhancing stakeholder representation is expected to provide more reliable insights. Although attempts have been undertaken to involve a wide range of stakeholders, it is imperative to acknowledge the potential constraints inherent in the breadth of interviews. To enhance the comprehensiveness of future research endeavours, broadening the pool of individuals interviewed may be imperative to embrace a more diverse array of opinions. This measure would guarantee that the system effectively caters to the diverse and complex requirements and anticipations of all parties involved.

Another factor limiting the research was legal limitations. The capacity to conduct direct interviews with households has been restricted due to legal requirements. The aforementioned limitations, which are crucial for protecting individuals' privacy and legal entitlements, impose restrictions on our ability to understand the perspectives and experiences of end-users inside households. To address this constraint, we have utilised other methodologies and sought input from additional stakeholders and desk research to enhance the comprehensiveness of our assessment.

The last factor is the lack of resources to assess the legal context fully. Considering the geographical dispersion of the system's stakeholders, who are situated in several countries and are subject to distinct legal frameworks and rules, it is very advisable to involve the expertise of a legal professional. The knowledge of legal experts in this field is crucial for conducting comprehensive evaluations of legal documents and guaranteeing full adherence to system-wide regulations, especially when dealing with the intricate aspects of international legal norms and

obligations.
In summary, these constraints highlight some of the complexities and difficulties that are associated with academic research in socio-technical systems and system engineering in general due to requiring multiple domains to collaborate to achieve a common goal (Konrad & Böhle, 2019). It is crucial to acknowledge and overcome these limitations in future research endeavours to improve the comprehensiveness and validity of our findings by combining research efforts from various domains. This will ensure that our results accurately reflect the complex nature of the system and its operational environment.

8.6. Future research topics

One important area for future investigation is refining the system architecture designed expressly for clean cooking initiatives. Given the promising outlook of information systems in these projects and the project's relation to tackling concerns related to the environment and health, it is crucial to enhance the system architecture in order to deploy the system. A practical implementation of the system is an essential research component. The empirical validation of this study will offer significant insights into the system's functioning, practicality, and flexibility within the specific context of clean cooking projects. A pilot of this nature ought to be undertaken in cooperation with essential stakeholders, such as local communities, clean cooking organisations, and regulatory bodies, to guarantee a thorough evaluation of its practicality in real-world scenarios. This procedure will additionally provide insights into potential obstacles and possibilities for improvement.
The second pivotal domain of study revolves around stakeholder involvement and system acceptance in the context of clean cooking initiatives, focusing on the role of verification and certification entities. To facilitate the effective incorporation of information systems into clean cooking initiatives, it is imperative to thoroughly examine the various players involved, encompassing governmental entities, non-governmental organisations, and industry participants, to engage them in the system design process actively. The study should investigate the extent to which verification and certification authorities are inclined and prepared to collaborate with information systems. The verification and certification processes are crucial in ensuring the dependability and compliance of clean cooking solutions with global standards and quality criteria. Examining how these entities can be incorporated into the system development process is of utmost importance. This study should aim to comprehensively examine the various motivations, obstacles, and cooperation procedures that are necessary for effectively engaging verification and certification bodies. Exploring mutual benefit should also examine how information technology can effectively speed up verification processes, alleviate administrative costs, and boost transparency for these organisations. This, in turn, can contribute to the better acceptance and market availability of clean cooking solutions.
An essential area for future research involves thoroughly analysing the transnational legal regulations requiring compliance while incorporating information systems in clean cooking initiatives. Given the frequent cross-border nature of these efforts and their adherence to a complex network of international regulations, it is crucial to involve legal professionals with

the necessary expertise to traverse and evaluate the convoluted legal framework effectively. The aforementioned areas of future research are expected to be fundamental to the future success of information systems in clean cooking projects.

8.6.1. Enhancing Research Methodology

In addition to the above-mentioned future research recommendations, the author suggests improvement on design science research methodologies. Both approaches combined by the author exhibit a similar structural framework; however, they diverge significantly in the level of detail they provide for implementation. Design Science Research Methodology (DSRM) furnishes a high-level depiction of artefact generation for research purposes. While DSRM aligns with the objectives of this research, it lacks granularity in the execution of individual steps within the design cycle. The selected systems engineering approach offers comprehensive guidance to address this deficiency, breaking down DSRM design cycle steps into sub-steps. Nevertheless, adhering to the extensive detail of the systems engineering approach surpasses the available resources for this research project. Consequently, the author has selectively incorporated the systems engineering approach in areas necessitating deeper insight. This selective integration has resulted in varying levels of system abstraction within different design cycle steps, a situation deemed suboptimal. In light of this, the author recommends that DSRM research should emphasize the development of methodologies to address these challenges, particularly in the context of conceptual designs.

8.7. Ethical reflection and personal opinion

Clean cooking initiatives have arisen as possible undertakings in the pursuit of sustainable development, intending to address environmental and health issues such as indoor air pollution and deforestation (Diehl et al., 2018). This is particularly relevant in regions such as Rwanda. Nevertheless, it is crucial to conduct a thorough examination of the ethical aspects associated with these initiatives. Some of these aspects are discussed in the following paragraphs.

External Interference in Foreign Countries Implementing clean cooking initiatives in foreign countries raises ethical concerns about external intervention. Although the underlying motives may be commendable, the imposition of solutions by external entities can be perceived as a potential infringement upon the sovereignty and self-determination of the recipient nation (Schmidt, 2018). The question arises as to whether interventions should prioritise the needs and aspirations of the host community over external agendas, prompting the need for reflection.

Foreign Ownership on Local Enterprises The presence of foreign ownership in domestic enterprises, specifically in the context of pellet manufacturing firms in Rwanda, gives rise to ethical considerations about economic autonomy and ownership (Appiah-Kubi et al., 2020). There are concerns regarding the eventual beneficiaries of these endeavours. The ethical implications of the issue extend beyond its economic dimensions, encompassing power dynamics, the utilisation of resources, and the empowerment of local communities.

Pro-Poor Principle in Achieving Equitable Benefit Distribution The ethical problem arises from the lack of a transparent allocation of advantages stemming from clean cooking initiatives, thereby perpetuating existing inequalities and injustices. To tackle this issue, it is advisable to employ the pro-poor principle. This principle prioritises the most economically disadvantaged and marginalised groups within society to ensure that they receive significant advantages and gains from these initiatives (Ravallion & Chen, 2003).

Considering the intricacies associated with external interventions, ownership structures, and benefit distribution is imperative. From an ethical standpoint, the objective must be to create a fair and morally sound system to govern clean cooking initiatives to promote environmental sustainability, social justice, and community empowerment, specifically in the context of Rwanda.

8.8. CoSEM programme linkage

The CoSEM program provides a comprehensive academic curriculum focusing on the principles and methodologies of designing socio-technical systems. This research is strongly aligned with the curriculum of the CoSEM program, as it explores the creation of a system that is firmly embedded inside a technical, legal and social multi-actor context. The resulting artefact exemplifies the integration of advanced technical capabilities and thorough adherence to procedural and legal obligations while incorporating various stakeholder perspectives. This research aligns specifically well with the Information and Communication track in the CoSEM program. Fundamentals, such as architecture, service, and platform design are inherently connected to creating an information system architecture, which can be described as a platform. In conclusion, the CoSEM program has proven to be a crucial foundation for understanding and effectively managing the complexity of developing socio-technical systems and this research. This study, which is grounded in the Information and Communication field, represents a concrete manifestation of the ideas of the program. It utilises a wide range of concepts from several courses to create a technologically advanced system that is sensitive to the complexities of its legal and social environment.

References

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research*, *29*(28), 42539–42559. https://doi.org/10.1007/s11356-022-19718-6

Ackermann, F., & Eden, C. (2011). Strategic management of stakeholders: Theory and practice. *Long range planning*, *44*(3), 179–196.

Agahari, W., Ofe, H., & de Reuver, M. (2022). It is not (only) about privacy: How multi-party computation redefines control, trust, and risk in data sharing. *Electronic markets*, *32*(3), 1577–1602.

Alhassan, I., Sammon, D., & Daly, M. (2016). Data governance activities: An analysis of the literature. *Journal of Decision Systems*, *25*(sup1), 64–75.

Allee, V. (N.d.). Value network analysis and value conversion of tangible and intangible assets. https://doi.org/10.1108/14691930810845777

Alshenqeeti, H. (2014). Interviewing as a Data Collection Method: A Critical Review. *English Linguistics Research*, *3*(1). https://doi.org/10.5430/elr.v3n1p39

Angelov, J. N. (2023). *Model-based systems engineering of flight control for vtol transition aircraft* [Doctoral dissertation, Technische Universität München].

Anjos, M. F., Feijoo, F., & Sankaranarayanan, S. (2022). A multinational carbon-credit market integrating distinct national carbon allowance strategies. *Applied Energy*, *319*, 119181. https://doi.org/10.1016/j.apenergy.2022.119181

Appiah-Kubi, S. N. K., Malec, K., Kutin, S. B., Maitah, M., Chiseni, M. C., Phiri, J., Gebeltová, Z., Kotásková, S. K., & Maitah, K. (2020). Foreign ownership in sub-saharan africa: Do governance structures matter? *Sustainability*, *12*(18), 7698.

Bao, J., He, D., Luo, M., & Choo, K.-K. R. (2020). A survey of blockchain applications in the energy sector. *IEEE Systems Journal*, *15*(3), 3370–3381.

Bayon, R., Hawn, A., & Hamilton, K. (2012a). *Voluntary Carbon Markets: An International Business Guide to What They Are and How They Work*. Taylor & Francis.

Bayon, R., Hawn, A., & Hamilton, K. (2012b). *Voluntary carbon markets: An international business guide to what they are and how they work*. Routledge.

Ben Arfi, W., & Hikkerova, L. (2021). Corporate entrepreneurship, product innovation, and knowledge conversion: The role of digital platforms. *Small Business Economics*, *56*, 1191–1204.

Betz, R., Michaelowa, A., Castro, P., Kotsch, R., Mehling, M., Michaelowa, K., & Baranzini, A. (2022). *The carbon market challenge: Preventing abuse through effective governance*. Cambridge University Press.

Bisaga, I., & To, L. S. (2021). Funding and Delivery Models for Modern Energy Cooking Services in Displacement Settings: A Review. *Energies*, *14*(14), 4176. https://doi.org/10.3390/en14144176

Björkegren, D., & Karaca, B. C. (2022). Network adoption subsidies: A digital evaluation of a rural mobile phone program in rwanda. *Journal of Development Economics*, *154*, 102762.

Blumberg, G., & Sibilla, M. (2023). A Carbon Accounting and Trading Platform for the uk Construction Industry. *Energies*, *16*(4), 1566. https://doi.org/10.3390/en16041566

Bonnema, G. M., & Broenink, J. F. (2016). Thinking tracks for multidisciplinary system design. *Systems*, *4*(4). https://doi.org/10.3390/systems4040036

Botta, F., Dahl-Jensen, D., Rahbek, C., Svensson, A., & Nogués-Bravo, D. (2019). Abrupt Change in Climate and Biotic Systems. *Current Biology*, *29*(19), R1045–R1054. https://doi.org/10.1016/J.CUB.2019.08.066

Botta-Genoulaz, V., Millet, P.-A., & Grabot, B. (2005). A survey on the recent research literature on erp systems. *Computers in industry*, *56*(6), 510–522.

Braun, R., Benedict, M., Wendler, H., & Esswein, W. (2015). Proposal for Requirements Driven Design Science Research. https://doi.org/10.1007/978-3-319-18714-3{_}9

Bryson, J. M. (2004). What to do when stakeholders matter: Stakeholder identification and analysis techniques. *Public management review*, *6*(1), 21–53.

Carr, M. (2007). Mobile payment systems and services: An introduction. *Mobile Payment Forum*, *1*(12), 1–12.

Carter, N., Bryant-Lukosius, D., DiCenso, A., Blythe, J., & Neville, A. J. (2014). The Use of Triangulation in Qualitative Research. *Oncology Nursing Forum*, *41*(5), 545–547. https://doi.org/10.1188/14.ONF.545-547

Champion, W. M., & Grieshop, A. P. (2019). Pellet-fed gasifier stoves approach gas-stove like performance during in-home use in rwanda. *Environmental Science & Technology*, *53*(11), 6570–6579.

Chowdhury, M. J. M., Colman, A., Kabir, M. A., Han, J., & Sarda, P. (2018). Blockchain versus database: A critical analysis. *2018 17th IEEE International conference on trust, security and privacy in computing and communications/12th IEEE international conference on big data science and engineering (TrustCom/BigDataSE)*, 1348–1353.

De Reuver, M., Sørensen, C., & Basole, R. C. (2018). The digital platform: A research agenda. *Journal of information technology*, *33*(2), 124–135.

Delimatsis, P. (2021). Sustainable finance. *Encyclopedia on Trade and Environmental Law, Edward Elgar*.

Di Maio, M., Weilkiens, T., Hussein, O., Aboushama, M., Javid, I., Beyerlein, S., & Grotsch, M. (2021). Evaluating MBSE Methodologies Using the FEMMP Framework. *2021 IEEE International Symposium on Systems Engineering (ISSE)*, 1–8. https://doi.org/10.1109/ISSE51541.2021.9582465

Dib, O., Brousmiche, K.-L., Durand, A., Thea, E., & Hamida, E. B. (2018). Consortium blockchains: Overview, applications and challenges. *Int. J. Adv. Telecommun*, *11*(1), 51–64.

Diehl, J. C., van Sprang, S., Alexander, J., & Kersten, W. (2018). A Scalable Clean Cooking Stove Matching the Cooking Habits of Ghana and Uganda. *2018 IEEE Global Humanitarian Technology Conference (GHTC)*, 1–8. https://doi.org/10.1109/GHTC.2018.8601916

Eckhardt, J., Vogelsang, A., & Fernández, D. M. (2016). Are" non-functional" requirements really non-functional? an investigation of non-functional requirements in practice. *Proceedings of the 38th international conference on software engineering*, 832–842.

Eu - data protection overview. (2022). *DataGuidance*. Retrieved June 28, 2023, from https://www.dataguidance.com/notes/eu-data-protection-overview

Fairley, D., & Forsberg, K. (N.d.). System Lifecycle Process Models: Vee - SEBoK. https://sebokwiki.org/wiki/System_Lifecycle_Process_Models:_Vee

Filewod, B., Mercer, L., Pierfederici, R., & Groom, B. (2023). Response to the unfccc's a6. 4-sb005-a02 information note: Guidance and questions for further work on removals.

Freeman, O. E., & Zerriffi, H. (2014). How you count carbon matters: Implications of differing cookstove carbon credit methodologies for climate and development cobenefits. *Environmental science & technology*, *48*(24), 14112–14120.

Gai, K., Wu, Y., Zhu, L., Qiu, M., & Shen, M. (2019). Privacy-preserving energy trading using consortium blockchain in smart grid. *IEEE Transactions on Industrial Informatics*, *15*(6), 3548–3558.

Gill-Wiehl, A., Ray, I., & Kammen, D. (2021). Is clean cooking affordable? a review. *Renewable and Sustainable Energy Reviews*, *151*, 111537.

Gill-Wiehl, A., Kammen, D., & Haya, B. (2023). Cooking the books: Pervasive over-crediting from cookstoves offset methodologies. https://doi.org/10.21203/rs.3.rs-2606020/v1

Goldreich, O. (1998). Secure multi-party computation. *Manuscript. Preliminary version*, *78*(110).

Gregor, S., Chandra Kruse, L., & Seidel, S. (2020). Research perspectives: The anatomy of a design principle. *Journal of the Association for Information Systems*, *21*(6), 1622–1652. https://doi.org/10.17705/1jais.00649

Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS quarterly*, 337–355.

Harrell, S., Beltramo, T., Blalock, G., Kyayesimira, J., Levine, D. I., & Simons, A. M. (2016). What is a "meal"? Comparative methods of auditing carbon offset compliance for fuel-efficient cookstoves. *Ecological Economics*, *128*, 8–16. https://doi.org/10.1016/j.ecolecon.2016.03.014

Helminger, L., & Rechberger, C. (2022). Multi-party computation in the gdpr. *Privacy Symposium 2022: Data Protection Law International Convergence and Compliance with Innovative Technologies (DPLICIT)*, 21–39.

Helmke, G., & Levitsky, S. (2004). Informal institutions and comparative politics: A research agenda. *Perspectives on politics*, *2*(4), 725–740.

Hevner, March, Park, & Ram. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 75. https://doi.org/10.2307/25148625

Hinckel, E., Borsato, M., Schmidt, J., MacCari, F., Storrer, P., & Onofre, E. (2016). Driving product design and requirements management with SysML. *Advances in Transdisciplinary Engineering*, *4*, 1071–1080. https://doi.org/10.3233/978-1-61499-703-0-1071

Hirshorn, S. R., Voss, L. D., & Bromley, L. K. (2017). *NASA systems engineering handbook* (No. HQ-E-DAA-TN38707). National Aeronautics; Space Administration.

Holt, J. (2021). *Systems Engineering Demystified*. Packt Publishing Ltd.

Holt, J., Perry, S., Payne, R., Bryans, J., Hallerstede, S., & Hansen, F. O. (2015). A model-based approach for requirements engineering for systems of systems. *IEEE Systems Journal*, *9*(1), 252–262. https://doi.org/10.1109/JSYST.2014.2312051

Hsu, C., Lee, J.-N., & Straub, D. W. (2012). Institutional influences on information systems security innovations. *Information systems research*, *23*(3-part-2), 918–939.

IEEE Consumer Electronics Society, IEEE Society on Social Implications of Technology, Institute of Electrical and Electronics Engineers. Region 6, Institute of Electrical and Electronics Engineers. Santa Clara Valley Section, & Institute of Electrical and Electronics Engineers. (N.d.). *GHTC 2018 : IEEE Global Humanitarian Technology Conference : 2018 conference proceedings : DoubleTree By Hilton San Jose, California, USA, October 18-21, 2018*.

Inozemtsev, M. I., Sidorenko, E. L., & Khisamova, Z. I. (2022). *The platform economy*. Springer.

International Organization for Standardization. (2018). Systems and software engineering – System life cycle processes.

Jagger, P., & Das, I. (2018). Implementation and scale-up of a biomass pellet and improved cookstove enterprise in rwanda. *Energy for Sustainable Development*, *46*, 32–41.

Ji, C.-J., Hu, Y.-J., & Tang, B.-J. (2018). Research on carbon market price mechanism and influencing factors: A literature review. *Natural Hazards*, *92*, 761–782.

Jiang, Y., Zhou, Y., & Feng, T. (2022). A blockchain-based secure multi-party computation scheme with multi-key fully homomorphic proxy re-encryption. *Information*, *13*(10), 481.

Kapoor, K., Bigdeli, A. Z., Dwivedi, Y. K., Schroeder, A., Beltagui, A., & Baines, T. (2021). A socio-technical view of platform ecosystems: Systematic review and research agenda. *Journal of Business Research*, *128*, 94–108.

Kapurch, S. J. (2010). *Nasa systems engineering handbook*. Diane Publishing.

Keller, M. (2020). Mp-spdz: A versatile framework for multi-party computation. *Proceedings of the 2020 ACM SIGSAC conference on computer and communications security*, 1575–1590.

Kim, S.-K., & Huh, J.-H. (2020). Blockchain of carbon trading for un sustainable development goals. *Sustainability*, *12*(10), 4021.

Konrad, K., & Böhle, K. (2019). Socio-technical futures and the governance of innovation processes—an introduction to the special issue. *Futures*, *109*, 101–107.

Kossiakoff, A., Biemer, S. M., Seymour, S. J., & Flanigan, D. A. (2020). *Systems engineering principles and practice*. John Wiley & Sons.

Kreibich, N., & Hermwille, L. (2021). Caught in between: credibility and feasibility of the voluntary carbon market post-2020. *Climate Policy*, *21*(7), 939–957. https://doi.org/10.1080/14693062.2021.1948384

Kurtanović, Z., & Maalej, W. (2017). Automatically classifying functional and non-functional requirements using supervised machine learning. *2017 IEEE 25th International Requirements Engineering Conference (RE)*, 490–495.

Lai, R., & Chuen, D. L. K. (2018). Blockchain–from public to private. In *Handbook of blockchain, digital finance, and inclusion, volume 2* (pp. 145–177). Elsevier.

Lakshmi, K. K., Gupta, H., & Ranjan, J. (2017). Ussd—architecture analysis, security threats, issues and enhancements. *2017 international conference on infocom technologies and unmanned systems (trends and future directions)(ICTUS)*, 798–802.

Lamothe, M., Guéhéneuc, Y.-G., & Shang, W. (2021). A systematic review of api evolution literature. *ACM Computing Surveys (CSUR)*, *54*(8), 1–36.

Lee, L., Chowdhury, A., & Shubita, M. (2023). Impact of Paris Agreement on financing strategy: Evidence from global FPSO industry. *Technological Forecasting and Social Change*, *188*, 122266. https://doi.org/10.1016/j.techfore.2022.122266

Leenes, R., & Kosta, E. (2015). Taming the cookie monster with dutch law–a tale of regulatory failure. *Computer Law & Security Review*, *31*(3), 317–335.

Lehtiniemi, T., & Haapoja, J. (2020). Data agency at stake: Mydata activism and alternative frames of equal participation. *new media & society*, *22*(1), 87–104.

Li, R., Song, T., Mei, B., Li, H., Cheng, X., & Sun, L. (2018). Blockchain for large-scale internet of things data storage and protection. *IEEE Transactions on Services Computing*, *12*(5), 762–771.

Lu, J.-L., & Shon, Z. Y. (2012). Exploring airline passengers' willingness to pay for carbon offsets. *Transportation Research Part D: Transport and Environment*, *17*(2), 124–128.

Malaurent, J., & Karanasios, S. (2020). Learning from workaround practices: The challenge of enterprise system implementations in multinational corporations. *Information Systems Journal*, *30*(4), 639–663.

mars.nasa.gov. (N.d.). Command & Data-handling Systems - NASA — mars.nasa.gov [[Accessed 19-09-2023]].

Maurer, T., Skierka, I., Morgus, R., & Hohmann, M. (2015). Technological sovereignty: Missing the point? *2015 7th International Conference on Cyber Conflict: Architectures in Cyberspace*, 53–68.

Michaelowa, A., Hermwille, L., Obergassel, W., & Butzengeiger, S. (2019). Additionality revisited: guarding the integrity of market mechanisms under the Paris Agreement. *Climate Policy*, *19*(10), 1211–1224. https://doi.org/10.1080/14693062.2019.1628695

Micheli, M., Ponti, M., Craglia, M., & Berti Suman, A. (2020). Emerging models of data governance in the age of datafication. *Big Data & Society*, *7*(2), 2053951720948087.

Miller, J. (2008). Triangulation as a basis for knowledge discovery in software engineering. *Empirical Software Engineering*, *13*(2), 223–228. https://doi.org/10.1007/s10664-008-9063-y

Modin Larsson, L. (2018). A gdpr compliant address infrastructure mobile application for ugandan and rwandan users.

Monteiro, A., Ankrah, J., Madureira, H., & Pacheco, M. O. (2022). Climate Risk Mitigation and Adaptation Concerns in Urban Areas: A Systematic Review of the Impact of IPCC Assessment Reports. *Climate*, *10*(8), 115. https://doi.org/10.3390/cli10080115

Mutshinyalo, T., & Siebert, S. (2010). Myth as a biodiversity conservation strategy for the vhavenda, south africa. *Indilinga African Journal of Indigenous Knowledge Systems*, *9*(2), 151–171.

Ncube, C., & Lim, S. L. (2018). On systems of systems engineering: A requirements engineering perspective and research agenda. *Proceedings - 2018 IEEE 26th International Requirements Engineering Conference, RE 2018*, 112–123. https://doi.org/10.1109/RE.2018.00021

Negri-Ribalta, C., Noel, R., Herbaut, N., Pastor, O., & Salinesi, C. (2022). Socio-technical modelling for gdpr principles: An extension for the sts-ml. *2022 IEEE 30th International Requirements Engineering Conference Workshops (REW)*, 238–234.

Netherlands - data protection overview. (2023). *DataGuidance*. Retrieved June 28, 2023, from https://www.dataguidance.com/notes/netherlands-data-protection-overview

Nguyen, Q., Yuknis, W., Pursley, S., Albaijes, D., Haghani, N., & Haddad, O. (2008). A high performance command and data handling system for nasa's lunar reconnaissance orbiter. *AIAA SPACE 2008 Conference & Exposition*, 7926.

Ølnes, S., Ubacht, J., & Janssen, M. (2017). Blockchain in government: Benefits and implications of distributed ledger technology for information sharing.

Pacheco, C., García, I., & Reyes, M. (2018). Requirements elicitation techniques: a systematic literature review based on the maturity of the techniques. *IET Software*, *12*(4), 365–378. https://doi.org/10.1049/iet-sen.2017.0144

Patel, D., Britto, B., Sharma, S., Gaikwad, K., Dusing, Y., & Gupta, M. (2020). Carbon credits on blockchain. *2020 International Conference on Innovative Trends in Information Technology (ICITIIT)*, 1–5.

Peck, M. E. (2017). Blockchain world-do you need a blockchain? this chart will tell you if the technology can solve your problem. *IEEE Spectrum*, *54*(10), 38–60.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2014). A Design Science Research Methodology for Information Systems Research. *https://doi.org/10.2753/MIS0742-1222240302*, *24*(3), 45–77. https://doi.org/10.2753/MIS0742-1222240302

Perera, H., Hussain, W., Mougouei, D., Shams, R. A., Nurwidyantoro, A., & Whittle, J. (2019). Towards integrating human values into software: Mapping principles and rights of gdpr to values. *2019 IEEE 27th international requirements engineering conference (RE)*, 404–409.

Ravallion, M., & Chen, S. (2003). Measuring pro-poor growth. *Economics letters*, *78*(1), 93–99.

Richardson, A., & Xu, J. (2020). Carbon trading with blockchain. *Mathematical Research for Blockchain Economy: 2nd International Conference MARBLE 2020, Vilamoura, Portugal*, 105–124.

Rwanda - data protection overview. (2023). *DataGuidance*. Retrieved June 28, 2023, from https://www.dataguidance.com/notes/rwanda-data-protection-overview

Saraji, S., & Borowczak, M. (2021). A blockchain-based carbon credit ecosystem. *arXiv preprint arXiv:2107.00185*.

Schlag, N., & Zuzarte, F. (2008). Market barriers to clean cooking fuels in sub-saharan africa: A review of literature.

Schmidt, E. (2018). *Foreign intervention in africa after the cold war: Sovereignty, responsibility, and the war on terror*. Ohio University Press.

Schneider, L., Duan, M., Stavins, R., Kizzier, K., Broekhoff, D., Jotzo, F., Winkler, H., Lazarus, M., Howard, A., & Hood, C. (2019). Double counting and the Paris Agreement rulebook. *Science*, *366*(6462), 180–183. https://doi.org/10.1126/science.aay8750

Schubotz, D. (2019). Participatory research: Why and how to involve people in research. *Participatory Research*, 1–264.

Shiping Chen, Harry Wang, & Liang-Jie Zhang. (2018). *Blockchain – ICBC 2018* (S. Chen, H. Wang, & L.-J. Zhang, Eds.; Vol. 10974). Springer International Publishing. https://doi.org/10.1007/978-3-319-94478-4

Singi, K., Choudhury, S. G., Kaulgud, V., Bose, R. J. C., Podder, S., & Burden, A. P. (2020). Data sovereignty governance framework. *Proceedings of the IEEE/ACM 42nd International Conference on Software Engineering Workshops*, 303–306.

Tamburri, D. A. (2020). Design principles for the general data protection regulation (gdpr): A formal concept analysis and its evaluation. *Information Systems*, *91*, 101469.

Uddin, G., & Robillard, M. P. (2015). How api documentation fails. *Ieee software*, *32*(4), 68–75.

United Nations, U. (2015). The Paris Agreement | United Nations. https://www.un.org/en/climatechange/paris-agreement

Uwamariya, M., & Loebbecke, C. (2020). Learning from the mobile payment role model: Lessons from kenya for neighboring rwanda. *Information Technology for Development*, *26*(1), 108–127.

Varvasovszky, Z., & Brugha, R. (2000). A stakeholder analysis. *Health policy and planning*, *15*(3), 338–345.

Ventrella, J., & MacCarty, N. (2019). Monitoring impacts of clean cookstoves and fuels with the Fuel Use Electronic Logger (FUEL): Results of pilot testing. *Energy for Sustainable Development*, *52*, 82–95. https://doi.org/10.1016/j.esd.2019.06.004

Vigolo, V., Sallaku, R., & Testa, F. (2018). Drivers and barriers to clean cooking: A systematic literature review from a consumer behavior perspective. *Sustainability*, *10*(11), 4322.

Walden, D. D., Roedler, G. J., Forsberg, K., Hamelin, R. D., Shortell, T. M., & Council, I. (2015). *Systems engineering handbook : a guide for system life cycle processes and activities*. Wiley.

Wang, Y., & Corson, C. (2015). The making of a ‘charismatic’ carbon credit: clean cookstoves and ‘uncooperative’ women in western Kenya. *Environment and Planning A: Economy and Space*, *47*(10), 2064–2079. https://doi.org/10.1068/a130233p

Wara, M. (2007). Is the global carbon market working? *Nature*, *445*(7128), 595–596.

Woo, J., Fatima, R., Kibert, C. J., Newman, R. E., Tian, Y., & Srinivasan, R. S. (2021a). Applying blockchain technology for building energy performance measurement, reporting, and verification (mrv) and the carbon credit market: A review of the literature. *Building and Environment*, *205*, 108199.

Woo, J., Fatima, R., Kibert, C. J., Newman, R. E., Tian, Y., & Srinivasan, R. S. (2021b). Applying blockchain technology for building energy performance measurement, reporting, and verification (MRV) and the carbon credit market: A review of the literature. *Building and Environment*, *205*, 108199. https://doi.org/10.1016/j.buildenv.2021.108199

Woo, J., Fatima, R., Kibert, C. J., Newman, R. E., Tian, Y., & Srinivasan, R. S. (2021c). Applying blockchain technology for building energy performance measurement, reporting, and verification (MRV) and the carbon credit market: A review of the literature. *Building and Environment*, *205*, 108199. https://doi.org/10.1016/j.buildenv.2021.108199

Zhong, H., Sang, Y., Zhang, Y., & Xi, Z. (2020). Secure multi-party computation on blockchain: An overview. *Parallel Architectures, Algorithms and Programming: 10th International Symposium, PAAP 2019, Guangzhou, China, December 12–14, 2019, Revised Selected Papers 10*, 452–460.

Zuazua Ruiz, A., Martín Martín, J. M., & Prados-Castillo, J. F. (2023). The European Union facing climate change: a window of opportunity for technological development and entrepreneurship. *Sustainable Technology and Entrepreneurship*, *2*(2), 100035. https://doi.org/10.1016/j.stae.2022.100035

Grey Literature References

BioMassters. (N.d.). The clean cooking solution. *BioMassters*. Retrieved June 28, 2023, from https://www.biomassters.co/

FairClimateFund. (N.d.-a). Cooking as a business [Internal presentation, accessed 2023-05-21]. *FairClimateFund*.

FairClimateFund. (N.d.-b). Our approach. *FairClimateFund*. Retrieved May 21, 2023, from https://www.fairclimatefund.nl/en/about-us/our-approach

FairClimateFund. (N.d.-c). Our mission. *FairClimateFund*. Retrieved May 21, 2023, from https://fairclimatefund.nl/en/about-us/our-mission

GoldStandard. (N.d.). Vision and impact. *Gold Standard*. Retrieved June 28, 2023, from https://www.goldstandard.org/about-us/vision-and-mission

MimiMoto. (N.d.). Clean cooking for all. *Mimi Moto*. Retrieved June 28, 2023, from https://mimimoto.nl/

SustainCert. (N.d.). About us. *SustainCERT*. Retrieved June 28, 2023, from https://sustain-cert.com/about-us

A

Appendix A

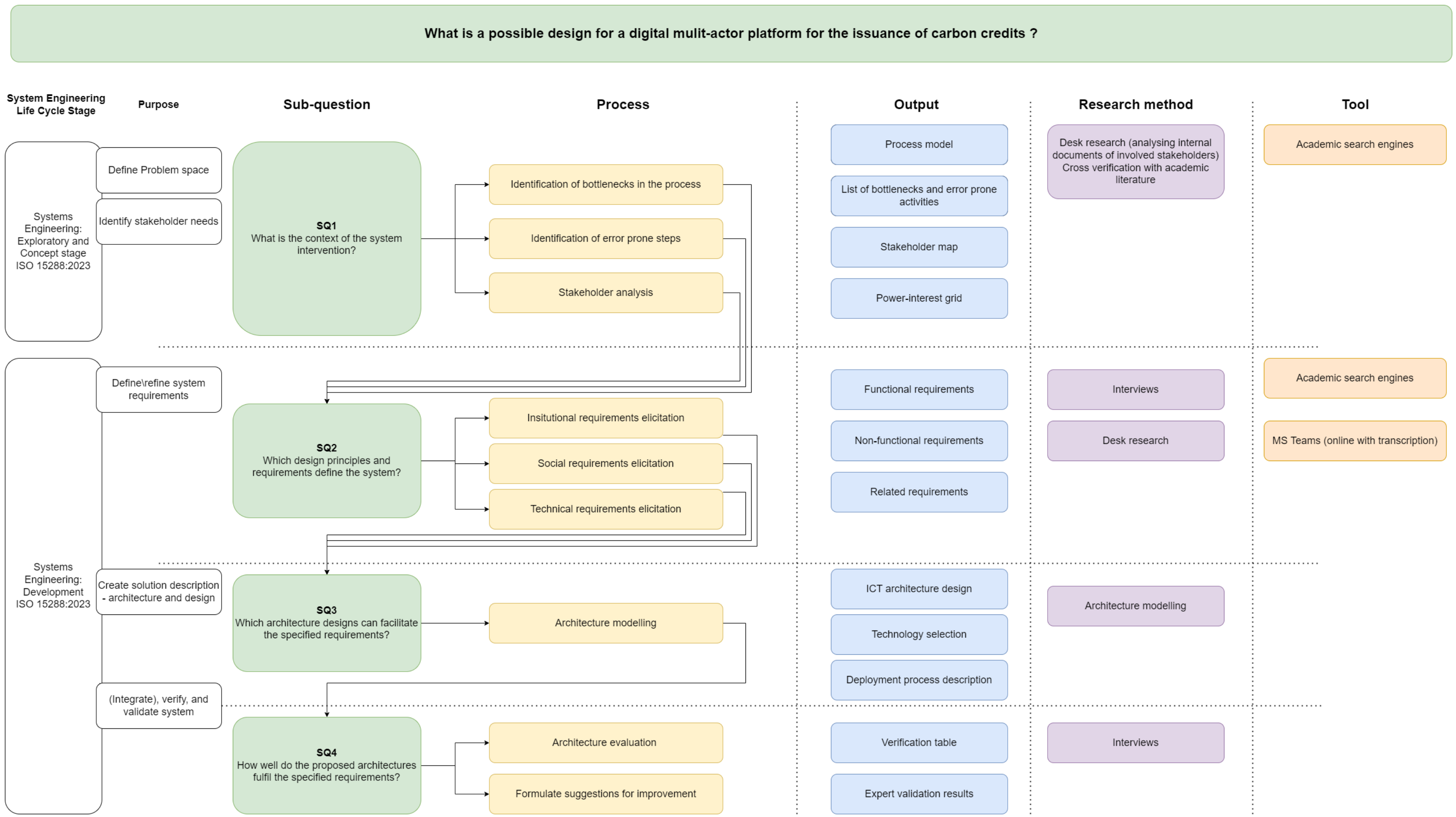

Figure A.1: Research Flow Diagram

B

Appendix B

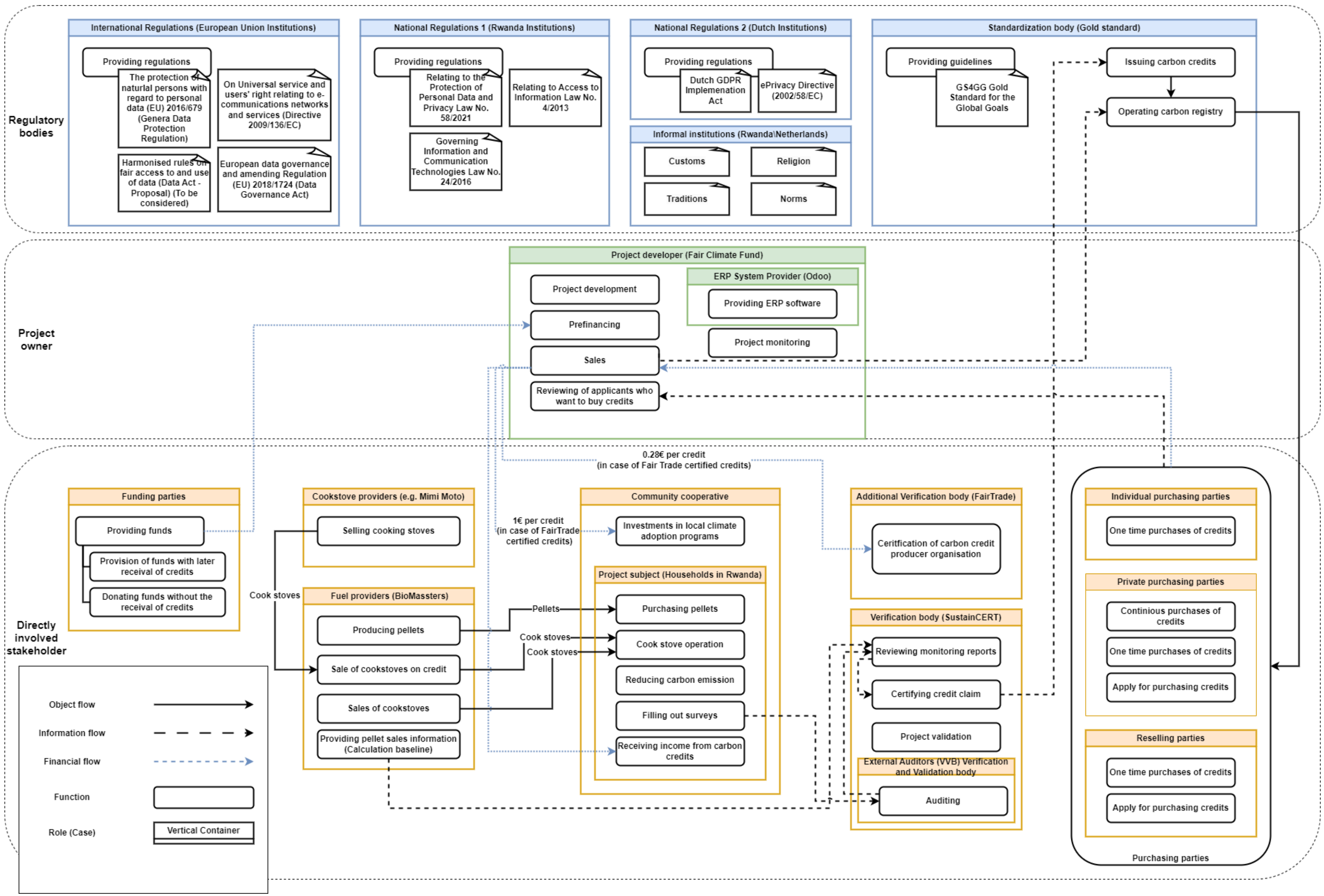

Figure B.1: System context diagram

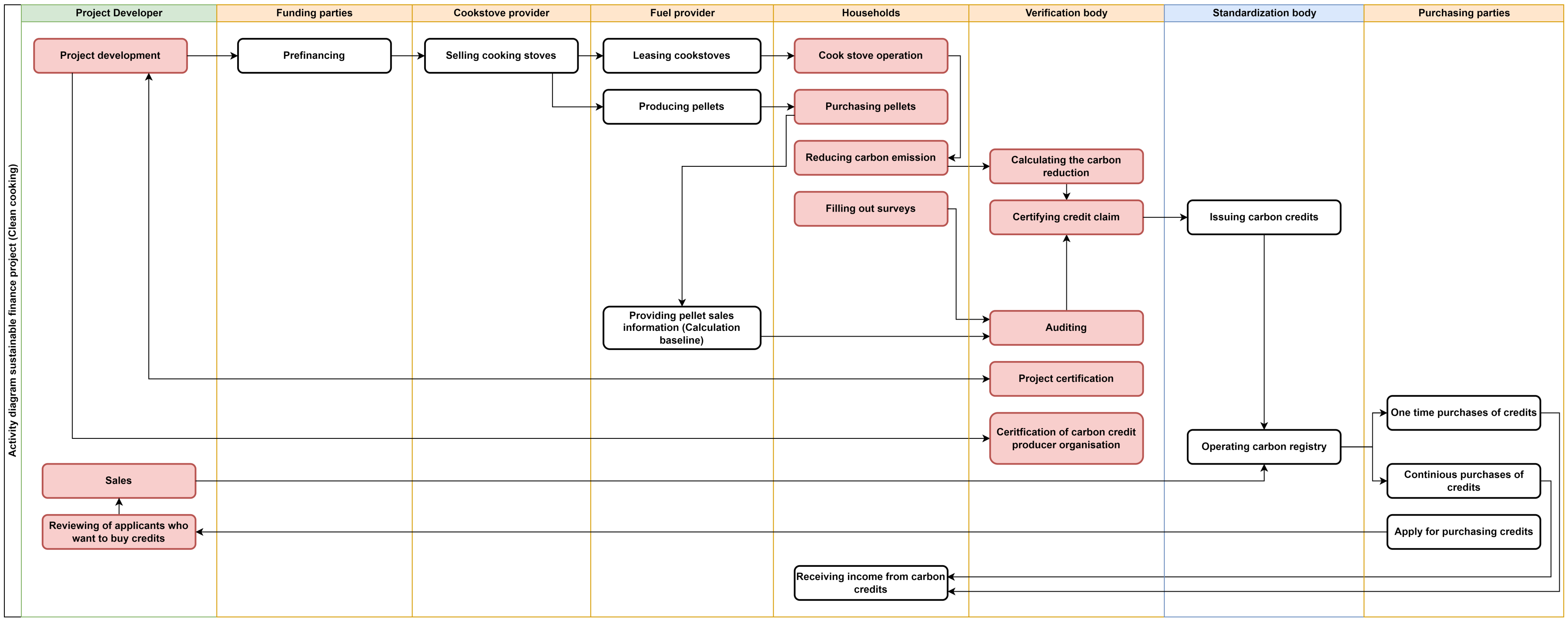

Figure B.2: Activity diagram excluding institutional stakeholders

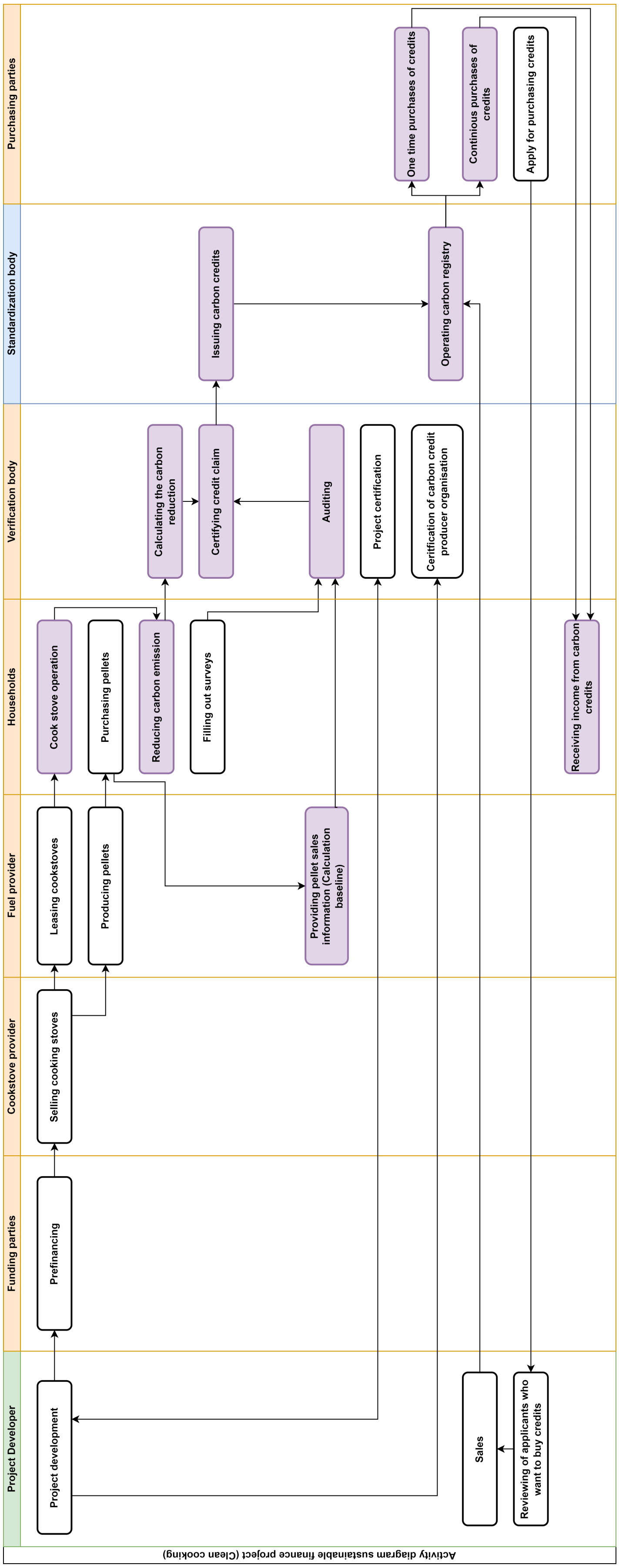

Figure B.3: Information system functionality

C

Appendix C

Index	Interviewee	Date and time	Protocol used	Type	Appendix
I1	Project developer	July 28th, 2023	IP1	Requirement elicitation	section C.2
I2	Purchasing party	August 11th, 2023	IP1	Requirement elicitation	section C.3
I3	Cookstove provider	August 1st, 2023	IP1	Requirement elicitation	section C.4
I4	Fuel provider	August 18th, 2023	IP1	Requirement elicitation	section C.5
I5	System Engineer	September 7th, 2023	IP2	Validation	section D.2
I6	Project developer	September 8th, 2023	IP2	Validation	section D.3

Table C.1: Interviews overview

C.1. (IP1) Interview protocol requirements elicitation

This Interview protocol was used to elicit requirements from the interviewed party. The protocol served as a foundation. However, deviations from the protocol were encouraged to enable the discovery of non-anticipated topics relevant to the interviewed party in the context of clean cooking projects. The interview protocol structure is shown in the following section.

Research objective The main objective of this interview is to elicit requirements from a party directly involved in clean cookstove projects.

Interview type Semi-structured interview

Interview Length and Format Approximately 45 to 60 minutes via video call

Interview steps

- Introduction of research
- Background information
  - Relationship of the interviewed party and clean cooking projects
- Understanding the current process
  - Are there any challenges or limitations in the process of your involvement in clean cooking projects currently or being anticipated?
- Requirements for the information system
  - Are there any features or functions you envision for the information system?
  - Are there any specific data points you would like to capture with the information system?
  - Are there any preferences or concerns regarding the system's usability and interface?
- Closing
  - Is there any additional insights or comments you may have?

C.2. (I1) Interview project developer summary

Date: July 28th, 2023

Channel: MS Teams

Overview: The interviewee represents the Fair Climate Fund, an organization involved in sustainable development projects. The interviewer seeks to gather information about the project developer's requirements and expectations for a digital platform to manage carbon emissions data from cookstoves and facilitate the carbon credit certification process.

Platform Functionality: The project developer envisions a platform to collect, manage, and verify carbon emissions data from cookstoves used in sustainable development projects. The platform should facilitate the certification process for carbon credits through compliance with standards such as Gold Standard and Fair Trade Climate Standard. Privacy regulations and concerns about sharing project participants' names and faces should be considered when designing the platform.

Data Collection and Transfer: Data should be collected from cookstoves in near real-time, with the possibility of monthly intervals for data transfer. Data transfer from cookstoves to the platform should be fully automated or seamless. The project developer acknowledges the cost considerations of real-time data transfer and emphasizes the importance of cost efficiency.

Scalability: The platform must be scalable to accommodate all projects the Fair Climate Fund undertakes in the future. The developer aims to connect all projects to the platform to streamline data collection and certification of carbon credit. Country-specific requirements and regulations may impact scalability plans and need to be considered.

Usability, Training, and Support: The platform should be user-friendly, self-explanatory, and easily accessible to project participants. User training will be necessary to collect accurate data and ensure the platform's practical use. Data analysis on the platform could help identify inconsistencies and abnormalities, contributing to more accurate project assessment and carbon credit calculation.

Cookstove Lifecycle and Replacement: The project developer acknowledges the need for cookstove replacements after a certain lifespan (around 3-5 years). Financial models for carbon credit payments could be used to fund replacements and encourage the continuous use of improved cookstoves. Compliance with Standards: The project developer emphasizes adherence to carbon certification standards, particularly Gold Standard and Fair Trade Climate Standard. Compliance with financial accounting standards is also essential, with annual audits conducted by accountants.

Conclusion: The project developer expresses the dynamic nature of the development process and the challenge of aligning ideas with changing regulations. Collaboration with other organizations developing similar technology is considered to avoid duplication of efforts.

C.3. (I2) Interview purchasing parties

Date: August 11th, 2023

Channel: MS Teams

Overview: The interviewee represents a company providing other organizations with information system hardware in the Netherlands. The company has purchased carbon credits previously.

Reasons for Purchasing Carbon Credits: The interviewee explains that the Dutch Government requires their organization to compensate for carbon emissions resulting from their operations. This results from directly supplying the Dutch government with hardware components. These supplier contracts by the Dutch government require the supplier to offset the emissions resulting from the operations necessary to supply the hardware.

Data and Verification Process: The interviewee explains that they provide a certification to the government as proof of their carbon credit purchase and offset. However, it is emphasized that tracking the actual impact and utilization of this data is challenging. The interviewee mentions another organization offering offsetting carbon emissions, which provides a dashboard showing the impact of carbon credit projects. The interviewee believes such a visual representation would be valuable for their organization.

Future Changes and Needs: The interviewee expresses the need for more transparency and visualization of the carbon credit impact, similar to the dashboard's functionality mentioned above.

Conclusion: The conversation concludes with the interviewee indicating they are receptive to information systems that provide more transparency, real-time tracking, and visualization of carbon credit impact.

C.4. (I3) Interview cookstove provider

Date: August 1st, 2023

Channel: MS Teams

Overview: The interviewee works for MimiMoto, a company that designs and produces Tier 4 cookstoves designed to work on compressed biomass pellets.

Carbon Reduction Monitoring: Carbon reduction in these projects is monitored using Gold Standard methodologies, which involve calculations based on fuel usage and cooking time.

Proposed Information System Features: The interviewee suggests that an information system could track the cooking time for each cookstove. Monitoring cooking time enables predictive maintenance and provides information on cookstove durability.

Integration with Information System: The interviewee discusses the challenges and benefits of integrating real-time monitoring with an information system. While real-time monitoring is possible, the practical implementation depends on the distributors' capabilities if the system still needs to be fully automated. The interviewee refers to the collection of data via fuel providers.

Ideal Integration and Considerations: The interviewee explains that while real-time monitoring is technically possible, costs must be weighed. The interviewee mentions an interest in exploring real-time monitoring options, potentially through memory chips or a more comprehensive network.

Conlcusion: The conversation highlights the challenges and opportunities in clean cooking projects and the potential benefits of integrating an information system for better monitoring and scalability.

C.5. (I4) Interview Fuel provider:

Date: August 18th, 2023

Channel: MS Teams

Overview This interview covers the perspective of the fuel provider on the information system under design.

Data Protection Laws in Rwanda The conversation commences with a discussion concerning data protection laws in Rwanda, which resemble the GDPR and compliance with one of the regulatory frameworks is also expected to resolve compliance issues with the counterpart.

Customer Management System (CRM) The interviewee provides an overview, explaining that the CRM system is designed to track customer data, contracts, sales, and interactions. Additionally, it facilitates cashback processes related to carbon credits, with all transactions conducted through the mobile money system.

Cashback System The interviewee elaborates on the cashback system, which offers customers financial incentives based on their clean cookstoves and pellets purchases. He underscores the integration of this system with the mobile money platform for seamless transactions.

Cookstove Usage Data Collection The interviewee mentions an ongoing trial involving GPS trackers embedded in stoves to gather usage data, which can then be correlated with pellet purchases. The primary objective of this initiative is to facilitate data analysis and gain insights into cooking patterns.

Insights from the Trial The interviewee provides insights into the ongoing trial, emphasizing its additional goal to validate the accuracy of usage data and discern cooking patterns. This includes understanding the duration of stove usage, typical cooking times, and variations in cooking patterns throughout the day.

Conclusions: In conclusion, this conversation delves into critical aspects of data protection compliance, the functionalities of the CRM system, the collection of cookstove usage data, and initial findings from the ongoing trial.

C.6. Requirements tables

Table C.2: Requirements grouped according to stakeholder

Stakeholder	Role occupant	Document\Interview	Index	Requirement (R)	Type
1 Project developer	Fair Climate Fund	Interview project developer	RF1.1	The system must collect, manage, and verify carbon emissions data from cookstoves.	Functional
			RF1.2	The system must enable data analysis to identify inconsistencies and to enable project assessment and carbon credit calculation.	Functional
			RF1.3	The system must reimburse project subjects financially.	Functional
			RF1.4	The system must transparently show all financial flows in the process of carbon credit issuance.	Functional
			RF1.5	The system must link carbon credits to the project subject and the project subject context such as region and community.	Functional
			RNF1.6	The system must facilitate scalability to encompass all future projects.	Scalability
			RNF1.7	The system must facilitate the certification process for carbon credits, adhering to standards such as Gold Standard and Fair Trade Climate Standard.	Compliance
			RNF1.8	The system must collect data from cookstoves in near real-time, or at least in reasonable intervals of 2-4 weeks.	Performance
			RNF1.9	The system must be designed to be user-friendly and self-explanatory for easy access by project participants.	Usability
			RNF1.10	The system must connect with CRM and ERP systems of stakeholders	Interface
2 Funding parties	N\A	N\A	N\A	N\A	
3 Cookstove provider	Mimi Moto	Interview cookstove provider	RF3.1	The system must enable data analysis for predicitve maintenance analysis.	Functional
4 Fuel provider	BioMassters	Interview fuel provider	RF4.1	The system must enable data analysis to more succesfully target project application areas.	Functional
			RNF4.2	The system must ensure free, prior and informed consent processes with people and local communities.	Process
5 Project subject	Rwanda households	Uwamariya, M., & Loebbecke, C. (2020). Learning from the mobile payment role model: lessons from Kenya for	RNF5.1	The system must tie in with the local payment mechanisms.	Interface

		neighboring Rwanda. Information Technology for Development, 26(1), 108-127			
		Schlag, N., & Zuzarte, F. (2008). Market barriers to clean cooking fuels in sub-Saharan Africa: a review of literature.	RNF5.2	The system must be encompassed with trainings on how it is used.	Process
		Vigolo, V., Sallaku, R., & Testa, F. (2018). Drivers and barriers to clean cooking: a systematic literature review from a consumer behavior perspective. Sustainability, 10(11), 4322.	RNF5.3	The system must be affordable for low income households.	Performance
		Diehl, J. C., van Sprang, S., Alexander, J., & Kersten, W. (2018, October). A scalable clean cooking stove matching the cooking habits of Ghana and Uganda. In 2018 IEEE Global Humanitarian Technology Conference (GHTC) (pp. 1-8). IEEE.	RNF5.4	The system must be easy to use and understand for users of all reasonable ages and levels of education.	Usability
		Filewod, B., Mercer, L., Pierfederici, R., & Groom, B. (2023). Response to the UNFCCC's A6. 4-SB005-A02 Information Note: Guidance and questions for further work on removals.	RNF5.5	The system must ensure free, prior and informed consent processes with people and local communities.	Process
6 Verification bodies	Gold Standard	Document: Site Visit and Remote Audit Requirements and Procedures	RF6.1	The system must enable communication with projects subject for verification bodies.	Functional
			RNF6.2	The system must document and provide evidence of the agreement mentioned in 6.3.	Process
			RNF6.3	The system must be subject to a mutual agreement between project developer, verification body and project subject for using it in remote assessments, following information security, data protection, and host country regulations.	Process
7 Purchasing parties	Computacenter	Interview purchasing parties	RF7.1	The system must provide projet impact visualization.	Functional
8 International institutions	European Institutions	The protection of naturlal persons with regard to personal data (EU) 2016/679 (Genera Data Protection Regulation)	RF8.1	The system must maintain documentation and demonstrate compliance with GDPR principles and regulations.	Functional
			RF8.2	The system must allow data subjects to request access to their personal data and provide it in a structured, commonly used, machine-readable format.	Functional
			RF8.3	The system must enable data subjects to request correction of inaccuracies in their personal data.	Functional
			RF8.4	The system must enable data subjects to request the deletion of their personal data under specific circumstances.	Functional

			RF8.5	The system must permit data subjects to object to specific data processing activities, including direct marketing.	Functional
			RF8.6	The system must facilitate data subjects' ability to receive their personal data in a portable format and transfer it to other services.	Functional
			RNF8.7	The system must provide clear, concise, and easily understandable information to data subjects about how their personal data will be processed, including the purposes, legal basis, retention period, and their rights.	Process
			RNF8.8	The system must establish security measures to ensure the integrity, and confidentiality of processed personal data while not storing data longer than necessary or needed for the defined purpose.	Compliance
			RNF8.9	The system must ensure that individuals are not subject to automated decisions without human intervention and must allow them to contest such decisions.	Compliance
		On Universal service and users' right relating to e-communications networks and services (Directive 2009/136/EC)	RNF8.10	The system must be compliant with the Directive 2009/136/EC.	Compliance
		Harmonised rules on fair access to and use of data (Data Act -Proposal) (To be considered)	RNF8.11	The system must be compliant with the Data Act - Proposal.	Compliance
		European data governance and amending Regulation (EU) 2018/1724 (Data Governance Act)	RNF8.12	The system must be compliant with the Data Governance Act.	Compliance
9 National Institutions 1	Rwanda Institutions	Relating to the Protection of Personal Data and Privacy Law No. 58/2021	RNF9.1	The data controller in the system must be registered with the Rwandan Cyber Security Authority.	Process
			RF8.1-RNF8.13		
		Governing Information and Communication Technologies Law No. 24/2016	RNF9.2	The system must be compliant with the Communication Technologies Law No. 24/2016	Compliance
10 National Institutions 2	Dutch Institutions	ePrivacy Directive (2002/58/EC)	RNF10.1	The system must be compliant with the ePrivacy Directive (2002/58/EC)	Compliance
		Dutch GDPR Implemenation Act	RF8.1-RNF8.13		
11 Infromal Institutions	Rwandan/Dutch Institutions	Customs/Religion/Traditions/Norms	RNF11.2	The system must be in line with customs, religion, tradition and norms given in the region and community.	Compliance

Table C.3: Requirements to functions mapping

	Logical system element/Process step	LSE1 Data handling system						LSE2 Communication system	LSE3 Payment system	LSE4 Visualization system		Deployment process					
		Personal data sovereignty (PDS)															
	Architectural choice/Process phases	Data sovereignty governance framework	Consortium -based distributed ledger technology		Multi-party computation (MPC)			External service (Enabling system)	Unstructured Supplementary Service Data (USSD)	External service (Enabling system)		Phase 1	Phase 2			Phase 3	Phase 4
	Function	F1 Raw data collection	F2 Data storage	F7 System behaviour tracking	F3 Data processing	F4 Carbon credit calculation	F6 Data control	F5 Stakeholder communication	F8 Payment facilitation	F9 Impact visualization	F10 Financial flow visualization	P1 Inform stakeholders on data usage	P2 Request consent from stakeholders	P3 Mutually agreement between project developer, verification body and project subject	P4 Register with the Rwandan Cyber Security Authority	P5 Document mutual agreement	P6 Conduct training on system usage
Index	**Requirement (R)**																
RF1.1	The system must collect, manage, and verify carbon emissions data from cookstoves.	F1															
RF1.2	The system must enable data analysis to identify inconsistencies and to enable project assessment and carbon credit calculation.				F3												
RF1.3	The system must reimburse project subjects financially.								F8								
RF1.4	The system must transparently show all financial flows in the process of carbon credit issuance.										F10						
RF1.5	The system must link carbon credits to the project subject and the project subject context such as region and community.	LSE1															
RNF1.6	The system must facilitate scalability to encompass all future projects.																
RNF1.7	The system must facilitate the certification process for carbon credits, adhering to standards such as Gold Standard and Fair Trade Climate Standard.																

RNF1.8	The system must collect data from cookstoves in near real-time, or at least in reasonable intervals of 2-4 weeks.	F1															
RNF1.9	The system must be designed to be user-friendly and self-explanatory for easy access by project participants.																
RNF1.10	The system must connect with CRM and ERP systems of stakeholders																
RF3.1	The system must enable data analysis for predicitve maintenance analysis.				F3												
RF4.1	The system must enable data analysis to more succesfully target project application areas.				F3												
RNF4.2	The system must ensure free, prior and informed consent processes with people and local communities.											P1	P2				
RNF5.1	The system must tie in with the local payment mechanisms.								F8								
RNF5.2	The system must be encompassed with trainings on how it is used.																P6
RNF5.3	The system must be affordable for low income households.																
RNF5.4	The system must be easy to use and understand for users of all reasonable ages and levels of education.																P6
RNF5.5	The system must ensure free, prior and informed consent processes with people and local communities.											P1					
RF6.1	The system must enable communication with projects subject for verification bodies.							F5									
RNF6.2	The system must document and provide evidence of the agreement mentioned in 6.3.															P5	
RNF6.3	The system must be subject to a mutual agreement between project developer, verification body and project subject for using it in remote assessments, following information security, data protection, and host country regulations.													P3			
RF7.1	The system must provide projet impact visualization.									F9							
RF8.1	The system must maintain documentation and demonstrate compliance with GDPR principles and regulations.															P5	

RF8.2	The system must allow data subjects to request access to their personal data and provide it in a structured, commonly used, machine-readable format.						P6										
RF8.3	The system must enable data subjects to request correction of inaccuracies in their personal data.						P6										
RF8.4	The system must enable data subjects to request the deletion of their personal data under specific circumstances.						P6										
RF8.5	The system must permit data subjects to object to specific data processing activities, including direct marketing.						P6										
RF8.6	The system must facilitate data subjects' ability to receive their personal data in a portable format and transfer it to other services.						P6										
RNF8.7	The system must provide clear, concise, and easily understandable information to data subjects about how their personal data will be processed, including the purposes, legal basis, retention period, and their rights.											P1					
RNF8.8	The system must establish security measures to ensure the integrity, and confidentiality of processed personal data while not storing data longer than necessary or needed for the defined purpose.																
RNF8.9	The system must ensure that individuals are not subject to automated decisions without human intervention and must allow them to contest such decisions.																
RNF8.10	The system must be compliant with the Directive 2009/136/EC.																
RNF8.11	The system must be compliant with the Data Act -Proposal.																
RNF8.12	The system must be compliant with the Data Governance Act.																
RNF9.1	The data controller in the system must be registered with the Rwandan Cyber Security Authority.														P4		
RNF9.2	The system must be compliant with the Communication Technologies Law No. 24/2016																
RNF10.1	The system must be compliant with the ePrivacy Directive (2002/58/EC)																

RNF11.2	The system must be in line with customs, religion, tradition and norms given in the region and community.																

D

Appendix D

D.1. (IP2)Interview protocol validation

The purpose of the interview structure that follows is to validate the different deliverables that are linked to every stage of the design cycle. This includes evaluating the context analysis in its entirety, defining the requirements, creating a logical and functional systems architecture, and choosing the right technologies.

Research objective The research objective is to comprehensively validate and refine the deliverables at each step of the design cycle by soliciting insights from both clean cooking project practitioners and systems architects, ensuring readiness for development.

Interview type Semi-structured interview

Interview Length and Format Approximately 45 to 60 minutes via video call

Interview steps

- Introduction of research
- Background information
    - Relationship of the interviewed party and clean cooking projects. Relationship of the interviewed party and information system architecture.
- Usability of deliverables
    - How valuable is the context analysis to your domain?
    - How valuable is the requirements elicitation to your domain?
    - How valuable is the system architecture to your domain?
    - How valuable is the technology selection to your domain?

- Closing
  - Are there any suggestions to improve the deliverables from your perspective?
  - Are there any additional insights or comments you may have?

D.2. (I5) Validation Interview Summary: Systems Engineer (Consultant)

Date: September 7th, 2023

Channel: MS Teams

Interview summary: During the interview conducted with a Systems Engineering Consultant employed at an IT firm in Germany, significant insights were obtained while assessing the information system architecture design. The assessment encompasses various components, including contextual analysis, requirements elicitation, and system architecture and design definition. The consultant placed significant emphasis on the imperative nature of redefining requirements before advancing to the phase of system design. This particular step holds significant importance as it guarantees the seamless alignment between the architectural design and the defined requirements and goals of the project. Additionally, the consultant emphasised the significance of utilising visual aids to present an overview since this can greatly improve stakeholders' comprehension of the system's architecture and capabilities. The utilisation of visual aids, within this particular context was perceived as crucial in fostering a shared comprehension among everyone involved in the project. Furthermore, the respondent highlighted the importance of incorporating a multi-actor perspective in the architectural design. This approach is fundamental to establishing a strong basis for accommodating the diverse roles and interactions of different stakeholders within the system. With respect to solution neutrality, the expert acknowledged its value; nonetheless, it was observed that the presentation of different solutions can yield advantageous outcomes. These alternate options not only offer a more comprehensive viewpoint but also assist in refining the design by examining many possibilities. In brief, the primary comments provided by the Systems Engineering Consultant emphasised two fundamental areas that require enhancement. Firstly, the necessity for the refining of requirements to establish a robust basis for system design. Furthermore, the necessity of performing a thorough cost analysis was recognised as crucial to making well-informed judgements and maximising the efficiency of the design. These observations emphasise the significance of thorough planning and analysis in developing efficient information system architectures.

D.2.1. Key findings:

- The consultant emphasised the importance of refining requirements before engaging in system design to ensure a successful deliverable when the information system is developed.
- The visual aids were considered to be crucial in building a collective comprehension of the system, hence facilitating stakeholders' comprehension of the structure and functionality of the design.

- The incorporation of a multi-actor perspective into the architectural design was commended for its ability to establish a robust framework that can effectively handle a wide range of stakeholder roles and interactions.
- The inclusion of alternative design methods can be advantageous as it promotes a more comprehensive understanding and aids in the refinement of the design by considering other options despite the preference for solution neutrality.
- The inclusion of a thorough cost analysis was recognised as an essential component to make well-informed judgements and maximise the efficiency of the design, underscoring the significance of considering financial limitations during the architectural process.

D.3. (I6) Validation Interview Summary: Project Developer

Date: September 8th, 2023

Channel: MS Teams

Interview summary: The researcher conducting the interview with a project developer for clean cooking projects, posed questions to the respondent regarding the usefulness of the provided artefacts during the research for an information system in a clean cooking project from the perspective of a project developer. In this discussion, the artefacts in question were referred to as ”a context analysis,” ”requirements,” ”system architecture,” and ”design definition.” The employee that was questioned is a developer on the project, and they claimed that all deliverables are beneficial. However, certain deliverables have an overwhelming amount of technical detail, which makes them difficult to understand. It would be useful if you could include that the individual who was interviewed suggested that all of the stakeholders review the deliverable. This would be helpful.

D.3.1. Key findings:

- The project developer indicated that all artefacts serve to enhance comprehension of both the design process and the system itself.
- It is advisable that all relevant parties engage in a comprehensive evaluation of the deliverables to ascertain their efficacy from all perspectives.
- From the point of view of a project developer who does not have competence in information systems, there are specific components of the deliverable that are described as being too ”technical.”