MSc thesis in Complex Systems Engineering and Management

Pathways to Sustainable Rural Electrification in Uganda: A Holistic Analysis of Techno-Economic, Socio-Technical, and Political Dimensions

From Policies to Action: Fostering Collaboration for Energy Development

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Pathways to Sustainable Rural Electrification in Uganda: A Holistic Analysis of Techno-Economic, Socio-Technical, and Political Dimensions

From Policies to Action: Fostering Collaboration for Energy Development

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To my mother and father,

For their unwavering dedication to our education.

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List of Abbreviations

BECS	Bundibugyo Energy Cooperative Society
ERA	Electricity Regulatory Authority
FiT	Feed-in-Tariff
GETFiT	Global Energy Transfer Feed-in Tariff
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GoU	Government of Uganda
IPPs	Independent Power Producers
KIL	Kilembe Investiment LTD
KIS	Kalangala Infrastructural Services LTD
KRECS	Kyegegwa Rural Electricity Cooperative Society
kWh/kWp	kilowatt hours per kilowatt peak
MCDA	Multi-Criteria Decision Analysis
MEMD	Ministry of Energy and Mineral Development
PACMECS	Pader-Abim Community Multi-Purpose Electric Cooperative Society
PPP	Public Private Partnerships
PV	Photovoltaics
REA	Rural Electrification Agency
RED	Rural Electrification Department
REP	Renewable Energy Policy
RESP	Rural Electrification Strategy and Plan
SADC	Southern African Development Committee
SDG	Sustainable Development Goal
UEDCL	Uganda Electricity Distribution Company Limited
UEGCL	Uganda Electricity Generation Company Limited
UETCL	Uganda Electricity Transmission Company Limited
UMEME	means 'elecrticity' in Swahili
W/m^2	Watts per meter squared
WENRECO	West Nile Rural Electrification Company LTD

Abstract

Decision-making about sustainable energy development often constitutes not only choices about which technology to adopt but also the dependencies of these technological choices on the social, economic and political helms within the context they are applied. For Uganda, juggling some of the country's innate challenges like poverty and lack of energy access whilst managing limited resources magnifies the complexity of its development efforts. Thus, crafting actionable policies and strategies to achieve the country's development goals requires a harmonious interplay of the country's social, technical, economic and political perspectives. Literature on sustainable energy development encompassing the different perspectives is growing. However, there is a knowledge gap in research that covers all the mentioned perspectives for Uganda.

This research focuses on rural electrification because rural communities comprise 74% of the country's total population and hold the key to attaining the country's sustainable energy development goals. From this, we derive the main research question: ***What are the plausible pathways for rural electrification development in Uganda, considering the techno-economic, socio-technical, and political perspectives, using a serious game?*** The main aim for including a serious game in this research is to study the tool's potential in streamlining the multi-faceted decision-making process. A pre-existing game was selected and adapted to the Ugandan context to include institutional roles, the choice of suitable rural electrification technology and other subsidy measures. The information needed for the adaptations was gathered using a mixed methods analysis approach. The information included Uganda's feasible energy generation alternatives, the criteria for analysis of the different generation alternatives and the main actors in the arena. This was done through reviews of relevant policies, surveys and interviews with relevant stakeholders. The findings from the game, which constitute adapting institutional roles, the choice of suitable rural electrification technology and other subsidy measures, were then proposed. The game also proved to be a beneficial tool to foster learning and collaboration amongst relevant energy stakeholders.

1 Introduction

1.1 Problem Definition

The United Nations' Sustainable Development Goal (SDG) 7 strives to ensure universal access to clean and affordable energy, aiming ultimately for sustainable energy development (SED) that drives economic growth, social development, and environmental and health protection (Gunnarsdottir et al., 2021; UNSDG, 2022). Achieving this goal involves addressing various interconnected themes, such as establishing sustainable energy sources, making modern energy services affordable and accessible, promoting responsible energy consumption, and ensuring energy security (Gunnarsdottir et al., 2021). However, the approach to implementing SED plans can differ significantly across nations and energy systems, underscoring the importance of tailoring analyses to the specific context in which they are to be applied. This study centres on Uganda, a nation in the Eastern region of Africa, specifically examining its endeavours, catalysts, and challenges in pursuing its sustainable energy development (SED) objectives. Uganda is an intriguing case study due to its abundance of renewable and oil resources, juxtaposed against one of the world's lowest energy consumption rates per capita of 215 kWh/PC (compared to the global average of 2,975 kWh/PC). Additionally, only 42% of its population has access to electricity, and a mere 5% have access to clean cooking technologies (Energy Profile: Uganda, 2022; Fashina et al., 2018).

Uganda has a substantial renewable energy capacity estimated at 7,200 MW, harnessed from hydroelectricity, geothermal energy, biomass, solar energy and peat. However, despite this potential, the country predominantly depends on wood fuel biomass, constituting 93% of the Total Energy Supply. This is followed by petroleum, both imported and non-renewable, and then electricity generated by hydropower (Fashina et al., 2018; PROBICOU et al., 2011). The heavy reliance on wood fuels has resulted in the depletion of forests and land degradation. Furthermore, the impacts of climate change have also posed challenges to hydropower generation (PROBICOU et al., 2011), and international fossil fuel prices and fuel supply constraints make thermal power generation expensive (MEMD, 2023). Parallel to energy generation challenges, the other formidable hurdles contributing to the country's low energy levels are a constrained transmission and distribution infrastructure and poor commercial utility practices that fail to effectively distribute the generated electricity country-wide (PROBICOU et al., 2011). The obstacles mentioned above are difficult for the country to rectify due to the pervasive poverty, which has been exacerbated by global disasters like the COVID-19 pandemic, as well as record-high energy and food prices resulting from the Russian invasion of Ukraine (IEA, 2022).

To address some of these challenges, the Government of Uganda (GoU) constituted several reforms and recognised strategies to address the nation's energy landscape. These initiatives have formed the blueprints of the country's energy policies, including the restructuring of its energy sector, and the institution of several laws and sub-policies to govern the exploitation of renewable and non-renewable energy assets to increase energy supply (Micheal et al., 2018; Nafuna, n.d.).

Nonetheless, several critical barriers remain that hinder the realisation of the envisioned outcome. For example, while the focus has been placed on solving supply-side challenges, demand-side challenges, such as high-end-user power tariffs, which marginalise many of the poorer population, still need to be addressed (PROBICOU et al., 2011). Additionally, although the petroleum sector, which is strongly backed by political will, is expected to boost Uganda's economy and increase government revenue, the finitude of the resource highlights the need for investment in more sustainable resources. Moreover, the "unbundling" of Uganda's energy sector, with divided responsibility for generation, regulation, and distribution, has presented coordination challenges among stakeholders with varying interests (Micheal et al., 2018).

The challenges mentioned above are multi-faceted. They include context-specific technical, economic, social and political aspects and multi-actor decision-making processes that must be assessed to develop viable pathways for the country to achieve its SED goals.

1.2 Knowledge Gap and Main Research Question

The main themes identified in Uganda's energy policy are synchronous with the traditional single-objective decision-making primarily concerned with maximising or minimising a particular element. Nevertheless, energy planning in the era of sustainable development has grown more complex due to the consideration of technical, social, economic and environmental aspects, putting significant constraints on decision-makers to optimise alternatives independently and discretely (Kumar et al., 2017).

This section analyses the literature on the development of policy recommendations in Uganda. Studies of other East African countries were also included in the analysis owing to the similarities in the above-identified aspects of their energy sectors (Manirambona et al., 2022). From this, the gaps in academia were identified, described and used to formulate the main research question. The typical research approaches used in the reviewed literature also informed the current strategies employed for this study. The following section explains the selection criteria for the literature used, followed by definitions of key terms and an overview and discussion of the selected articles.

1.2.1 Literature Review

There is an emerging scholarship on the study of sustainable energy development within the African context, including sub-Saharan Africa and East Africa. For this paper, scientific was sourced from the SCOPUS database using the keywords *energy AND policy AND development OR implementation AND in AND Uganda OR East Africa,* which yielded 324 papers.

The papers were screened based on keywords to focus on energy policy, policy development and policy implementation with a limit on the geographical scope of Uganda and East Africa. This focused on literature that offered knowledge on viable policies or means of implementing the suggested policies. The results narrowed considerably to 35 papers. Whereas environmental concerns are considered for sustainable energy development, papers with this as their main foci were excluded as they do not fit directly into the presented perspectives. Technical research papers investigating the feasibility of a particular technology were also excluded.

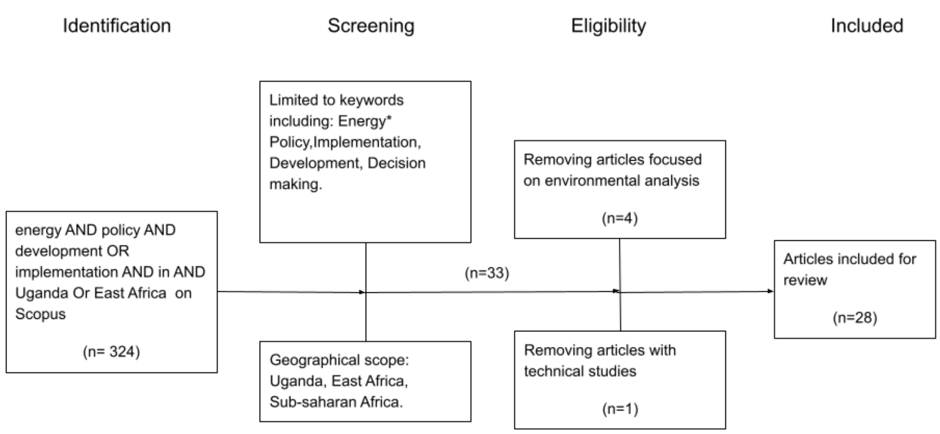

Figure 1 Literature Selection

1.2.2 Co-evolution of disciplines

Closely linked to sustainable energy development is the energy transition. The ever-increasing global demand for energy correlates with the emergence of alternative forms of energy and the need to reduce the over-reliance on fossil fuels. This need stems from the acknowledgement that greenhouse gases must be reduced worldwide. As a result, the paradigm is shifting towards renewable energy sources (Lyu et al., 2022).

Authors Cherp et al. (2018) and Apfel (2022) emphasise that a successful energy transition goes beyond the changes in individual energy technologies or fuel sources but should consider the energy system as a whole, much like the previous section for sustainable energy development. Cherp et al. 2018 streamline and combine these seemingly distinct disciplines (technology, energy systems, economics, sociology and political science) into techno-economic, socio-technical and political perspectives.

Techno-economic perspective

The techno-economic perspective is rooted in energy systems analysis and various economic domains. It focuses on the connection between generation from existing natural systems and consumption through trade of different energy services valued by societies (such as lighting and mobility). The idea of supply-demand equilibrium is frequently used in conjunction with the neoclassical economic concept of market equilibrium from the techno-economic perspective. The concept holds that under competitive markets, energy supply and use are in a stable equilibrium as long as consumers are not willing to pay a different price for energy or producers are not willing to supply it at a different cost (Cherp et al., 2018). Neoclassical economics can explain the stability of energy systems and some of their changes. For instance, resource depletion results in higher extraction costs, which may prompt the use of alternative resources, more efficient machinery, or reduced consumption, or population growth results in higher demand, which may also prompt the use of alternative supply options (Cherp et al., 2018).

Most of the techno-economic theories deal with quantitative variables that can be used to set targets and goals. However, they usually fall short of answering whether real-life policymakers can pursue these goals. Therefore, they do not consider the required objects for analysis, understanding and explanation.

Socio-technical perspective

Socio-technical is based on the sociology of technology, socio-technical systems and evolutionary economics. It focuses on technical change or adoption, especially the emergence and diffusion of new technologies. It looks more at the nuances in the interactions of technology and the social aspects explaining technological changes. The authors identify two major strands of research with the socio-technical perspective relevant to energy systems: technological innovation systems studies and the socio-technical transition analysis.

The technological innovation system studies are mainly concerned with emerging novel technologies. Although such studies initially focused on the possible market failures of these innovations, the studies have since expanded to include the institutional and organisational changes that need to occur with technology development (Markard et al., 2012). These studies are also better suited to inform policymaking in that they include identifying drivers and barriers to innovation, paving the way for more technology-specific policies (Markard et al., 2012).

The second strand, the socio-technical transition analysis studies, 'adopt a broad sociological frame, combined with practical interest in historical methodologies' (Turnheim et al., 2015). A central concept to these studies is the socio-technical regime combining ideas and concepts from evolutionary economics, history and sociology of technology to highlight that scientific knowledge, engineering practices, and process technologies are socially embedded. In other words, they are seamlessly intertwined with the expectations and skills of technology users, institutional structures, and broader infrastructures. In summary, socio-technical system literature is centred on how new configurations emerge and are retained in society (Coenen & Lopez, 2010). This same focus on novelty is one of the main limitations of this perspective, as it leads to an oversight of already existing technologies that require incremental or no innovation at all.

Political Perspective

Political perspective is based on political science. Within the energy sector, the focus is on formulating and implementing policies that affect the energy system. Because most energy policies are adopted and implemented by governments acting on behalf of nation-states, **the state** is the main unit of analysis. This perspective is a distinct domain from the other two in that rather than looking at state actors as ordinary economic actors, external 'landscape' factors or recipients of normative recommendations; they are the primary focus of analysis.

From the political perspective, the central concept is that of institutions, i.e., the structures and rules that enable and constrain the state and other political actors. The authors also share two dimensions by which the state can be conceptualised, i.e., state-centric and state-structural. State-centric approaches assume that states are autonomous actors pursuing national interests or state imperatives, as was briefly described in the introduction of this research and later in the energy sector overview in the following chapters. In comparison, the state-structural approach assumes that states' policies reflect competing interests of domestic actors such as voters, political parties, social movements and industrial lobbies.

Literature Overview

Table 1.1 below presents an overview of the current literature on sustainable energy transitions within the East African context, employing the above-presented perspectives for their analysis. The paper titles were included to provide insight into the scope of the literature.

Table 1 Literature Overview

Reference	Title	Perspective	Interviews
Lo and Kibalya (2023)	Electric cooperatives and the political economy of rural electrification in Africa: Insights from Uganda	political	surveys
Woolley et al. (2022)	Domestic fuel affordability and accessibility in urban Rwanda; policy lessons in a time of crisis?	socio-technical,	hybrid optimization model
Sohail et al. (2022)	A comprehensive scientometric analysis of hybrid renewable energy systems in developing regions of the world	techno-economic	Qualitative analysis/ Literature review
Manirambona et al. (2022)	A review of sustainable planning of the Burundian energy sector in East Africa	socio-technical, techno-economic and political	literature review, GIS tools
Choti and Xydis (2022)	Harnessing offshore wind energy in East Africa: the next big move to lighting up the continent	techno-economic, political	literature review
Mugisha et al. (2021)	Assessing the opportunities and challenges facing the development of off-grid solar systems in Eastern Africa: The cases of Kenya, Ethiopia, and Rwanda	socio-technical, tecno-economic	Policy document analysis, interviews
Galuszka et al. (2021)	East Africa's policy and stakeholder integration of informal operators in electric mobility transitions—Kigali, Nairobi, Kisumu and Dar es Salaam	techno-economic	Scenario Capacity Expansion Model (System Planning Test)

Reference	Title	Perspective	Interviews
Kiprotich et al. (2021)	Exploring the Implication of Renewable Energy Transition on the Cost of Electricity and Green House Gases Emission in East African Countries	techno-economic	case-studies
Kovacic et al. (2021)	Building capacity towards what? Proposing a framework for the analysis of energy transition governance in the context of urban informality in Sub-Saharan Africa	socio-technical	Qualitative Document Analysis/Interviews/Closed Surveys
Stritzke et al. (2021)	Towards responsive energy governance: Lessons from a holistic analysis of energy access in Uganda and Zambia	political	Policy Review (Qualitative)
Mabea (2020)	Electricity market coupling and investment in renewable energy: East Africa Community power markets	techno-economic	Policy Review (Qualitative)
Kahunzire et al. (2020)	Beyond carbon emissions: A system of systems approach to sustainable energy development in East Africa	techno-economic	Surveys, Literature reviews
Muchunku et al. (2018)	Diffusion of solar PV in East Africa: What can be learned from private sector delivery models?	socio-technical, techno-economic	Literature review
Roopnarain and Adeleke (2017)	Current Status, hurdles and future prospects of biogas digestion technology in Africa	techno-economic, socio-technical	Literature Review
Khadam et al. (2016)	The establishment of electricity market structure in East African countries	techno-economic	Qualitative Literature Review
Hansen et al. (2015)	Review of Solar PV policies, interventions and diffusion in East Africa	techno-economic	Quantitative analysis (Lang factor)
Ndyabawe and Kisaalita (2014)	Validity of the Africa-wide Lang factor of 2.63 for estimating small biogas plant installation costs in Uganda	techno-economic	literature review, interviews
Ondraczek (2013)	The sun rises in the East (of Africa): A Comparison of the Development and Status of solar energy markets in Kenya and Tanzania	techno-economic	interviews, literature reviews, questionnaires, industry experience
Mwampamba et al. (2013)	Opportunities, challenges and way forward for the charcoal briquette industry in Sub-Saharan Africa	techno-economic	technical study
Mechtenberg et al. (2012)	Human power (HP) as a viable electricity portfolio option below 20W/Capita	socio-technical, techno-economic	case-studies

Reference	Title	Perspective	Interviews
Buchholz and Volk (2012)	Considerations of Project Scale and Sustainability of Modern Bioenergy Systems in Uganda	techno-economic, socio-technical	surveys, interviews, focus groups
Walekhwa et al. (2009)	Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications	socio-technical,	Interviews
Mwirigi et al. (2009)	Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya	socio-technical; advised for multi-disciplinary research	Strategic Niche Market Tool
Van Eijck and Romijn (2008)	Prospects for Jatropha biofuels in Tanzania: An analysis with Strategic Niche Management	techno-economic	Spreadsheet model
Buskirk and Robert (2006)	Analysis of long-range clean energy investment scenarios for Eritrea, East Africa	techno-economic	policy
Scholz (2006)	Sustainable Energy Services - A new energy policy for Sida	political, techno-economic	Workshop
Arvidson and Woodsworth (2006)	A regional energy scale-up initiative in East Africa	political	Qualitative analysis/ Literature review
Murphy (2001b)	Making the energy transition in rural East Africa: Is leapfrogging an alternative?	socio-technical, political and techno-economic	Interviews

From the above overview, it becomes evident that most of the literature addresses no more than two of the abovementioned perspectives, with the political viewpoint receiving less attention. Given the constraints elucidated previously regarding focusing solely on any one of the perspectives, research that does not combine all three is compromised on its applicability and practicability of its results.

Of the referenced articles, only Manirambona et al. (2022) and Murphy (2001) make mention of all three perspectives. However, both papers are only reviews, and their recommendations are yet to be actuated in subsequent research. Furthermore, while most of the papers offer policy recommendations, only Manirambona et al. (2022) provide a means to include the social actors in exploring potential policy alternatives by using Multi-Criteria Decision Analysis (MCDA). Additionally, of the techno-economic studies, most of the literature focuses on the feasibility of single technological options. However, as previously noted, Uganda has a diverse potential for renewable energy sources.

Therefore, this research aims to fill these gaps in the literature by offering a comparative study of available resources and employing means to involve social and political actors in exploring different aspects from the three perspectives to ensure more sustainable energy planning. Unlike the MCDA recommendation by Manirambona et al. (2022), the means used in this study is a serious game, the details of which are elaborated in the following chapters.

1.2.3 Scope and Main Research Question

The scope of this research has been narrowed down to concentrate on rural energy development. Rural communities constitute approximately 74% of Uganda's population yet have an electricity access rate of only 35.9% (World Bank, n.d.). Hence, to achieve universal access to energy and attain sustainable energy goals, the disparities regarding rural energy development need to be overcome.

Institutional and policy arrangements exist for national electrification, including those explicitly tailored towards rural electrification. The central guiding policy for rural electrification is the Rural Electrification Strategy Plan II (RESP II), whose primary objective is *"To achieve an accelerated pace of electricity access and service penetration to meet national development goals during the planning period and beyond"* in order to increase the rural electrification rate to 26% by 2022 and electrify the whole country by 2040 (MEMD, 2013). The preceding policy strategy RESP I, which was centred on private sector-led rural electrification, was inhibited by the risk aversion of the private investors owing to the underlying economics of investing in electricity infrastructure in (rural) areas where people are poor and industrial activity is underdeveloped. In order to amend the failures of its predecessor, the new strategy employed several mechanisms, including government-centralized investment, a cooperative-driven model alongside the private sector model, and diversification of generation technologies to improve on-grid and off-grid access.

Therefore, combining the insights from the literature review and the sectoral institutions at play, the following main research question is presented: ***What are the plausible pathways for rural electrification development in Uganda, considering the techno-economic, socio-technical, and political perspectives, using a serious game?*** The aim is to analyse the country's current development through the lenses of different perspectives and integrate the findings into a serious game. By playing the game, we develop comprehensive and 'tested' pathways for rural electrification to assist with integrated decision-making for policymakers in the Ugandan and East African context.

2 Methodology

2.1 Research Approach

A significant number of the papers cited in the literature review employed a mix of qualitative methods such as interviews and literature reviews (e.g., Mugisha et al. (2021), Khadam et al. (2016) and Ondraczek (2013) and quantitative methods like surveys and use of models (e.g., Woolley et al. (2022), Woolley et al. (2022) and Kiprotich et al. (2021)) for their data collection and analyses.

The results obtained from the quantitative analyses commonly include recommendations for appropriate low-carbon technologies and cost-implication studies, which provide necessary information for decision-makers. However, despite the quantitative approach's relevant numerical data and evidence, it is not sufficient in its applicability and practicability. The nature of quantitative research can be described as deterministic, meaning causes probably determine effects and outcomes (Creswell, 2008). This also means that the input data, strategies and even the choice of model or survey questions for a study approach heavily affect the outcomes. Because of this, various quantitative studies on the topic can have variations in their results, which could compromise their overall credibility. As mentioned previously, another shortfall in quantitative research for this topic is that these mainly numerical results set targets and goals rather than objects for analysis, understanding and explanation (Cherp et al., 2018). They exclude an essential aspect, the local contexts and other interests of the decision-makers to implement their recommendations.

On the other hand, Research covering political perspectives and also some socio-technical studies (e.g., Lo and Kibalya (2023), Stritzke et al. (2021) mostly use qualitative methods like interviews and literature reviews for their data collection and analysis. This research approach helps cover the geographical or local context-specific information regarding the priorities, interests, and challenges of critical actors in the energy sector, including government officials, societal actors, and investors in the different energy sectors. The participatory outlook of this approach improves the practicality and may encourage the collaboration of actors in implementing recommendations from the study.

Therefore, to develop comprehensive research that encompasses the valuable information derived from both quantitative and qualitative approaches to research on this topic whilst steering away from their shortcomings, a Mixed-Methods approach will be used to conduct this study. Mixed methods research uses qualitative and quantitative approaches for breadth and depth of understanding and corroboration (Creswell & Clark, 2017). For each of the sub-questions later formulated, definitive conclusions will not be made at their end; instead, the mixed methods approach will entail treating the results of each sub-question as interim and be used as the entry data for the next stage in the research. Using both approaches in tandem has the advantage of improving the overall strength of the study as compared to using either one of the qualitative or quantitative methods.

Other guiding approaches have been included in this research, i.e. Multi-Criteria Decision Analysis (MCDA) and game theory, though neither constitutes the primary research approach. MCDA is a collection of formal approaches that seek to explicitly account for multiple criteria in helping individuals or groups explore decisions that matter (Belton & Stewart, 2012). The main goal of the approach is to assist decision-makers in learning about the issue at hand, about their own and others' values and judgments, and to assist them in identifying, frequently through extensive discussion, a preferred course of action by organising, synthesising, and appropriately presenting information (Belton & Stewart, 2012). This method was considered in the advisement of Manirambona et al. (2022), especially for selecting different generation technologies. For this study, the steps used in MCDA, i.e., 1) Problem Structuring; 2) Determining the requirements; 3) Establishing Goals; 4) Identifying Alternatives; 5) Defining criteria; 6) Selecting a decision-making tool; 7) Evaluating alternatives against criteria and finally 8) Validating solutions against problem statement were used to order the steps for conducting the research and developing the sub-questions. No specified MCDA methods (i.e., value function, generalised goal programming, and outranking methods) were used.

The use of a serious game is central to the findings of this research. The game played by employees in the sector is meant to mimic the decision-making process for rural electrification, including the selection of the different generation technologies. Serious games are broadly described as games for non-entertainment purposes and often utilise educational and behavioural change as crucial drivers for usage (De Freitas & Ketelhut, 2014). Whereas the development of a serious game is based on gaming theory, we are not developing a serious game from scratch, as such gaming theory cannot be said to be a methodology used. Instead, a pre-existing game will be used, and the deployment of which replaces the MCDA methods from the steps above.

2.1.1 Sub-Questions

This section discusses the breakdown and steps based on the MCDA research structure used to conduct the study. The main research question is "***What are the plausible pathways for rural electrification development in Uganda, considering the techno-economic, socio-technical, and political perspectives, using a serious game?"***

Hence, four sub-questions have been formulated to answer the main research question, for which the relevance, data requirements and qualitative or quantitative methods are used to derive an answer. The answers to each sub-questions form incremental and sequential steps towards answering the main research question.

Sub-question 1: What alternatives are available for electricity generation based on the requirements and goals of Uganda's energy policies?

In order to determine the requirements, goals and alternatives available for rural electrification in Uganda (steps two, three and four of the MCDA process), we look at the prevailing energy policy documents and reports, associated scientific literature and stakeholder inputs from a survey.

From this analysis, we can derive a set of criteria (step 5 of the MCDA process) for evaluating the electricity generation resources and technologies. The electricity generation sources and technologies (the alternatives) mentioned in the policy are often based on these criteria. However, their usability is determined by other factors such as sufficiency to meet demand, location specificity or maturity of technology. The factors used are based on scientific literature and stakeholder inputs. Thus, the second deliverable from this sub-question is a refined list of generation technologies that will be considered for use in the serious game.

Sub-question 2: Who are the critical actors and stakeholders within the realm of rural electrification in Uganda?

The primary function of this sub-question is to determine the stakeholders within the rural electrification sector, i.e., those who make the decisions and those who are affected by or are interest groups for the decisions made. The identified actors will form the roles to be played during the game.

The stakeholders are identified through an energy sector analysis, which also includes understanding their interactions within the system. A stakeholder analysis will be conducted, and from this, the individual objectives of the actors can be generated. From this, we may also understand the hierarchy of decision alternatives being considered. The stakeholder analysis can be considered part of the problem framing (step one), and the different objectives also make up the criteria for the different options.

The system analysis will be done through a desk review of policy documents, reports, newspapers and scientific articles. These documents contain information drawn from interviews, news articles and political agendas of governmental institutions. Additionally, interviews will be conducted with some identified actors to assess their objectives or interests and enabling or blocking power.

Sub-question 3: What is the required structure of the selected pre-existing game?

Under advisement, the thesis period was insufficient for the complete design of a new game. Thus, a pre-existing game will be used for this research. The game is the main tool of analysis (step six of the MCDA process); as such, particular attention needs to be paid towards the choice made. The selected game must accommodate the analysis of the techno-economic, socio-technical and political perspectives and provide enough leeway to fit the necessary interactions and actors for the specific context.

The adjustments will be based on information from the previous sub-questions and the overview of the Ugandan energy sector, accommodating the three perspectives. Finally, it is also essential that the game is available for use and easily accessible, given the resource restrictions for the research. Based on these requirements, readily available games will be sourced and selected from literature and serious game databases to be compared for final selection.

Sub-question 4: How do stakeholder decisions affect Uganda's energy mix, and can serious games enhance their decision-making?

The main objective for including a serious game in this research is to study the potential of the tool's use in streamlining the multi-faceted decision-making process regarding sustainable energy development. The other benefit this research hopes to reap from using the game is for the stakeholders to learn more about the moving parts within the sector and, by doing so, be better equipped to develop solutions and policies to overcome the sector's other challenges. To achieve this, stakeholders in the energy sector will play the game, including employees of the Ministry of Energy and private distribution and power companies.

During the gameplay, players must choose from the electricity generation alternatives; however, the choices individual players make are based on their pre-determined goals within the game. These individual goals are based on the criteria derived from sub-question two for the individual stakeholders. However, it is important to remember that other broader sets of criteria are also based on the sector's goals and requirements, which are determined in sub-question one. Therefore, in playing the game and balancing between the overall and individual objectives, the stakeholders are evaluating the alternatives against what may be two different sets of criteria.

Following the chronological order of the MCDA process, the gameplay is the seventh step to determine the weights for the different criteria. This part of the formal MCDA process is arguably the most difficult because of its heavy dependence on the stakeholders' participation. It is prone to disruption due to the high cognitive load, biases, unconstructed preference and limited participation (Aubert et al., 2018) (because it is time-consuming or needs a facilitator). However, gaming allows players to learn about alternatives and explore the consequences within a safe trial-and-error environment. The gamification offers an engaging and challenging frame that encourages players' (stakeholders') involvement in comprehensive learning whilst supporting deliberation and decision-making.

After playing the game, the stakeholders/players will be asked questions through discussion, interviews and a questionnaire based on their experience and game results. These questions will aim to determine three main impacts:

1. The prevailing criteria or objectives that drive decisions made regarding energy development and whether or not these are beneficial in meeting the overall objectives.
2. The best ways forward in meeting the overall objectives. The results from the question constitute answering the main research question.
3. They will also be asked questions about their overall experience with gaming, which will inform the tool's usefulness and future adoption within the Ugandan context.

2.2 Social and Scientific Relevance

Energy is a crucial catalyst for sustainable development. Consequently, a lack of access to reliable energy constrains individual and societal prospects and overall well-being. This is proven by the explicit inclusion of targets such as access to affordable, reliable, sustainable, and modern energy for all by 2030 to the Sustainable Development Goals (SDGs). However, for many African policymakers and societies, striking a balance between the pertinent need for a sustainable energy sector and strained domestic expenditures and low household incomes (IEA, 2022) is an evident dilemma. This confirms the need for more studies that offer actionable strategies to assist with integrated decision-making about energy and other sectors in the African context.

On the scientific front, the contribution of this paper is two-fold. Firstly, to realise its sustainable energy development goals, Uganda, like many other developing countries, has adopted institutions and policies that are successful from other nations. Little is documented in the literature about the impact and effectiveness of this *institutional transplantation*. The term institutional transplantation is defined by Mamadouh et al. (2002) as the literal borrowing of political institutions, business fashions, management practices and policies from one country to another. A few of the rural electrification strategies described in later chapters fall under this category, and even the proposed use of a serious game, in a sense, is an attempt at the transplantation of a relatively novel Western tool whose viability for the Ugandan context will be tested. Secondly, the use of a serious game in this research assists with the possible adoption of these valuable learning and collaborative tools among policymakers outside of the Western world, where a number of serious game initiatives are concentrated (De Freitas & Ketelhut, 2014).

2.3 Structure of the Report

The listed research questions are addressed through seven separate chapters in the thesis. Chapters One and Two are introductory. Chapter One includes an overview of the research problem and a literature review that leads to the main research question, and chapter two describes the research methodology, approaches and design. Chapter Three presents an overall system analysis of the electricity sector in Uganda. While this research specifically focuses on rural electrification, the governance arrangement of the sector follows a top-to-bottom model, which makes it imperative to have a high-level analysis of the sector. The study, therefore, includes an overview of the institutional structure and relevant national policies from which the stakeholders and the considered electricity generation resources for the energy system are identified. The chapter comprises the first part of the data collection and answers sub-questions one and two, whose results are inputs for the game.

Following the system analysis, Chapter Four delves into the choice and development of the serious game. The chapter first presents the essential aspects that must be included in the game to validate its usefulness. Then, the steps taken during the game modification are described. The final sections of the chapter constitute the primary analysis of this research, wherein the game is played by workers within the electricity sector of Uganda.

Chapter Five is the Discussion chapter highlighting other plausible pathways towards universal energy access in Uganda. In the concluding chapters Six and Seven, the thesis objectives and sub-questions are reviewed, and the research questions are answered. The seventh chapter then offers recommendations based on the discussions in the previous chapter, and areas for further research are outlined.

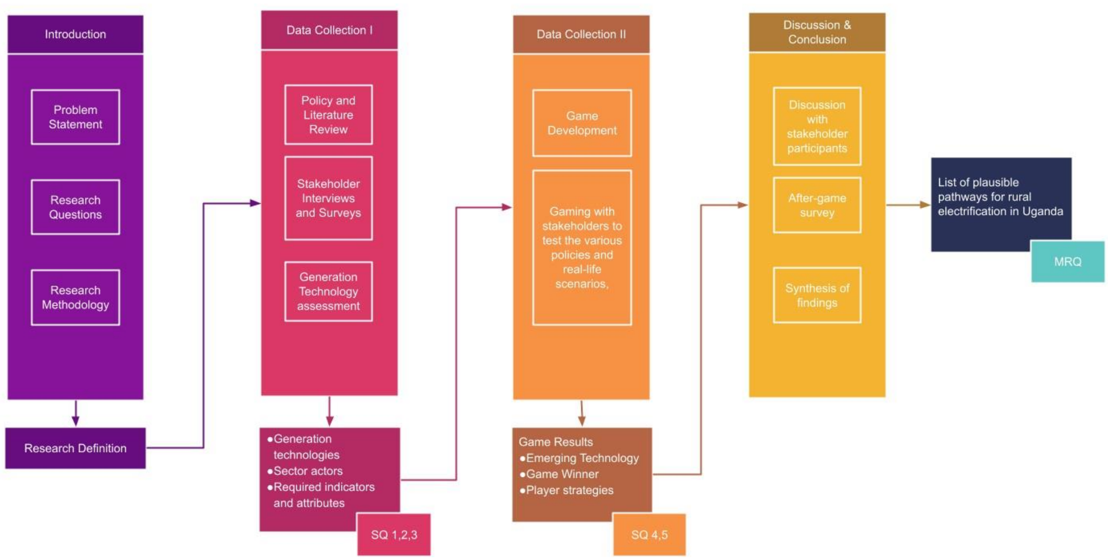

Figure 2 Research Flow Diagram

3 Overview of the Ugandan Electricity Sector

Uganda politically and economically reformed its energy sector, including a new legal and regulatory framework based previously on the vertically integrated monopoly, Uganda Electricity Board, that was unbundled, leading to public-private partnerships. The country's electricity sector was divided into Generation, Transmission and Distribution. The generation sub-sector combines government-owned power plants, Independent Power producers (IPPs), and Public-Private Partnerships (PPPs). Transmission is wholly owned and controlled by the government body, Uganda Electricity Generation Company Ltd (UEGCL). Like the generation segment, distribution has also been liberalised to include private players and the government-owned Uganda Electricity Distribution Company Ltd (UEDCL) (ERA, 2020).

The rural electrification institutional arrangement is spearheaded by the Ministry of Energy and Mineral Development (MEMD), the policy head of Uganda's Electricity Supply industry. The ministry's mandate is to establish and promote the development of Energy and Mineral resources for social and economic development. Answerable to the ministry is the Electricity Regulation Authority (ERA), which serves as the licensing and regulatory body for all electricity operators in the country (ERA, 2020), and the Rural Electrification Agency (REA), more recently streamlined into a department within the ministry, charged with operationalising the government's rural electrification goals [(*Energypedia*, n.d.), MEMD, 2023).

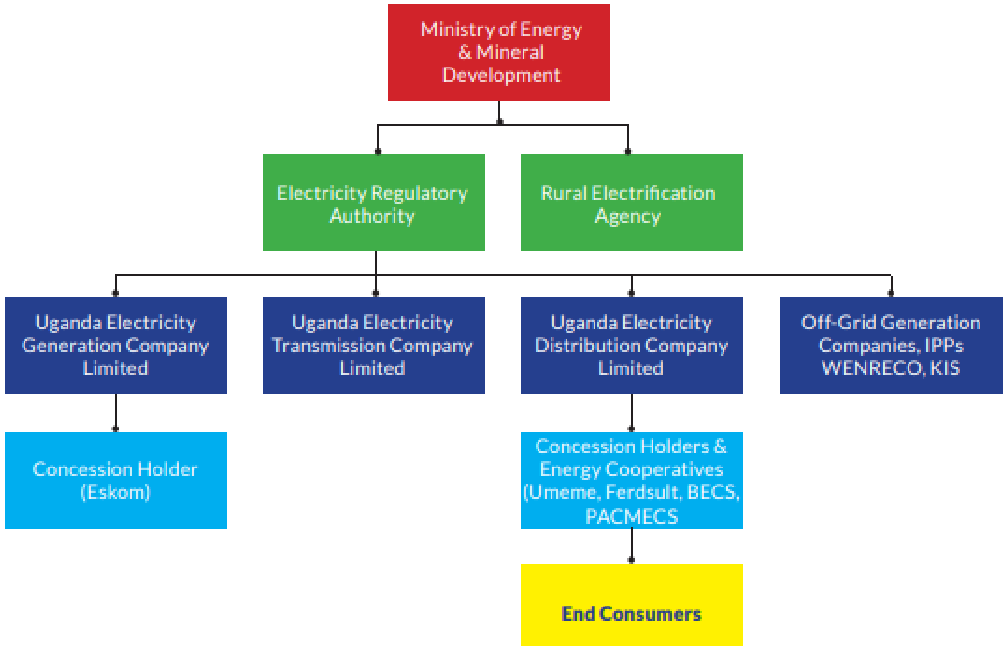

Figure 3 Institutional Framework (UEGCL, 2018)

3.1 Rural Electrification Strategy

The rationale behind the energy sector unbundling in Uganda was to introduce competition in the electricity generation and retail distribution market segments. Unbundling prevents cross-subsidization between competing and regulated businesses and avoids conflicts of interest from a single utility performing multiple functions. It promotes greater competition, efficiency, innovation, and risk management as new players enter the market. Unbundling also limits political influence and ensures a focus on company efficiency. In Uganda, unbundling has led to improvements in generation capacity, financial viability, consumer connections, and reliability in the power sector (Twesigye, 2022). However, challenges remain in electrification rates and supply reliability, which still require targeted policy solutions. First, we delve into the specific challenges facing rural electrification before we look at the policy steps implemented to facilitate the sector's development.

According to Holstenkamp's 2019 study on sustainable electrification in the global south, rural electrification presents several difficulties compared to urban or peri-urban electrification. These challenges arise due to lower incomes, a shortage of trained professionals, lower revenues from low initial demand, and higher investment and operating costs due to lower population density and load factor. These factors contribute to high uncertainties and low expected returns, making it economically challenging to undertake rural electrification projects within the short or medium term. Consequently, the focus shifts from pure cost recovery to addressing the needs of low-income people through "smart" subsidies. However, determining the availability and type of subsidies is a contested issue due to low willingness and ability to pay, competing development priorities, and the potential market distortion and dependency caused by donations. Additionally, predicting household demand is difficult, as it is influenced by varying socio-economic attributes. Larger organisations with assured demand, such as schools and government facilities, are often targeted to mitigate the challenges of low demand. It is increasingly recognised that promoting "productive use" programs and complementary initiatives alongside electrification is necessary.

Furthermore, technology adoption is influenced by local factors, economic feasibility, technical viability, customer perception, and political preferences. The choice between energy technologies, including sustainability, is influenced by fossil fuel subsidies and the lack of internalisation of external effects. Donor policies have evolved from technology diffusion to market creation, albeit with donor-specific technology preferences and approaches. As emphasised by Holstenkamp (2019), these challenges necessitate comprehensive strategies and collaboration to address financial constraints, skilled workforce shortages, demand unpredictability, and technology adoption barriers to achieve rural electrification successfully.

The Government of Uganda (GoU) and the MEMD developed the Rural Electrification Strategy Plan (RESP I & II) to develop rural electrification. RESP I (2001- 2010), led by the liberalisation efforts at the time, included the adoption of a private sector-led rural electrification model, focusing on the provision of capital grants for the construction of grid infrastructure in rural areas, as well as enabling market penetration of the productive use of electrical equipment and appliances (Lo & Kibalya, 2023). Similar strategies focussing on the private sector have been deployed in other developing countries, as recorded by Yadoo and Cruickshank (2010), with varying success levels. Examples include dealer networks offering consumer credit schemes for solar home systems in Kenya, the creation of concessionary areas for rural electrification in north-west Argentina, and assisted development of emerging retail markets for local energy service companies in India, Sri Lanka and Laos.

However, following the economic challenges as highlighted, coupled with the high initial capital costs and the profit-centrism of the investors over social development, private sector-led initiatives are prone to failure, as was the case in Uganda. The government, therefore, formulated a new strategy, the RESP II (2013-2022), based on the lessons learned from the first plan.

3.1.1 RESP II - A multi-pronged strategy

The primary objective of RESP II was **"***To achieve an accelerated pace of electricity access and service penetration to meet national development goals during the planning period and beyond"* to increase the rural electrification rate to 26% by 2022 and electrify the whole country by 2040. The significant themes in RESP II addressed the challenges mentioned above and more broadly fit into the techno-economic, socio-technical and political perspectives. Some of the more notable mechanisms in the new strategy included a shift toward government-centralised investment, a cooperative-driven model alongside the private sector model, and diversification of generation technologies to improve on-grid and off-grid access.

The following sections detail the mechanisms mentioned above for RESP II. The time frame for the plan has passed, and while no official reports are yet to be released on the most current progress, interim publications and analyses have been shared. These, as well as other related literature, have been used to compile these sections. The section on **Cooperatives in Uganda** and the **Selection of generation technologies** comprise the first part of the data collection through desk research and stakeholder interviews.

The section on Cooperatives begins with a brief description and introduces the intended roles of these players in RESP II. Their positioning as well in this top-to-bottom model of governance is also explained. Finally, we look at some challenges these players face in carrying out their prescribed roles.

For the available generation resources and technologies, The first step was to compile a resource assessment study on available energy sources based on literature, mainly from Uganda's energy resource policies and industry expert inputs. Furthermore, a list of criteria for the different energy generation sources was obtained from the literature review.

A questionnaire and survey were shared with stakeholders in Uganda's energy sector. The stakeholders comprise employees from MEMD and private entities working in electricity efficiency, generation, distribution, and social engagement. A total of eight participants were engaged and were involved in the participatory processes, including the game.

The questionnaire survey was divided into three parts: the first part sought the stakeholders' perception of the most viable energy sources to be exploited for rural electrification. The second part asked for their assessment of the more essential indicators when selecting these generation technologies. Finally, the interviewees were asked about the objectives, opportunities and challenges they face in their operations precisely regarding rural electrification, the information of which was used in another section of the paper.

3.2 Cooperatives in Uganda

The cooperative models can be defined as approaches to providing electricity where the local community owns or co-owns the means of generation, transportation/distribution, or sale of electricity (Holstenkamp, 2019). The cooperative-driven approach was included for RESP II to address the underlying business risk private sector investors face.

As the beneficiary population, cooperatives and their members are seen as the most motivated stakeholders in driving rural electrification. The strategy involves these groups in setting local priorities, managing demand integration and consumer outreach, and managing and operating electrification schemes. Besides combating the lack of interest in utility and investment, cooperatives can overcome barriers relating to social integration and acceptance of Renewable Energy (RE) technologies, end-user education and after-sales services and enhance local maintenance capabilities. Hence, these community-based initiatives pose drivers for greater energy autonomy and security, as well as building social capital and pursuing sustainability objectives (Madriz-Vargas et al., 2018).

As a result of the policy, the country curated a highly diversified electricity distribution sector (see Table 2 below). Of the eight listed below, three are cooperatives: Bundibugyo Energy Cooperative Society (BECS), Pader-Abim Community Multi-Purpose Electric Cooperative Society (PACMECS), and Kyegegwa Rural Electricity Cooperative Society (KRECS)

Table 2: Electric Distributors and their service territories (Lo & Kibalya, 2023)

Service Territory	Districts	Distributor
Central ST	Kyegegwa[8], Mubende[2,4], Kyankwanzi[2], Kiboga[2], Nakaseke[2], Nakasongola[2,4], Luwero[2], Kayunga[2], Mukono[2], Mityana[2], Kampala[2], Buikwe[2], Wakiso[2], Mpigi[2]	KRECS, UMEME, UEDCL
Central North ST (CNST)	Otuke[2], Kole[2], Lira[2,4], Aleptong[4],Apac[2,4],Dokolo[4], Kaberamaido[4], Amolatar[4]	UEDCL
Eastern ST (EST)	Buyende[2,4], Kamuli[2], Jinja[2], Luka[2], Kaliro[2], Pallisa[2], Budaka[2], Kibuku[2], Butalejja[2], Namutumba[2], Iganga[2], Bugiri[2], Mayuge[2,4], Busia[2], Tororo[2], Manafwa[2], Bududa[2], Mbale[2], Sironko[2]	UEDCL, UMEME
Midwestern ST (MWST)	Ibanda[4], Mbarara[2], Kiruhura[2,4], Lwengo[2], Bukomansimbi[2], Sembabule[4], Gomba[2], Kalungu[2], Butambala[2]	UEDCL, UMEME
North Eastern ST (NEST)	Moroto[4], Amudat[4], Bukwo[2], Kapchorwa[2], Kween[2], Bulambuli[2], Bukedea[2], Nakapiripirit[4], Katakwi[2], Kumi[2], Ngora[2], Serere[2], Soroti[2], Amuria[2]	UEDCL, UMEME
Northwest (NNWST)	Moyo[4], Adjumani[2,4], Amuru[2,4], Nwoya[2], Oyam[2], Gulu[2]	UEDCL, UMEME
North West ST (NWST)	Kiryandongo[2,4], Buliisa[4], Masindi[2], Hoima[2], Kibale[4], Kyenjojo[4], Kamwenge[4]	UMEME, UEDCL
Northern	Kaabong, Lamwo[2], Kitgum[2], Pader[7], Agago[7], Abim[7], Kotido	UMEME, PACMECS
Rwenzori	Ntoroko[6], Bundibugyo[6], Kabarole[2]	BECS, UMEME
South ST (SST)	Ntungamo[2,4], Isingiro[2,4], Rakai[4], Masaka[2,4]	UEDCL, UMEME
South western ST (SWST)	Rukungiri[2,4], Kanungu[4], Kisoro[2,4], Kabale[2,4]	UEDCL, UMEME
West Nile	Koboko[1], Yumbe[1], Maracca[1], Arua, Zombo[1], Nebbi[1]	WENRECO
Western	Kasese[2,3], Rubirizi[4], Buhweju[2,3], Bushenyi[2,3], Mitoma[,2,4], Sheema[2,3]	KIL, UMEME, UEDCL
Kalangala	Kalangala[5]	KIS

[1]WENRECO (West Nile Rural Electrification Company LTD); [2]UMEME, [3]KIL (Kilembe Investiment LTD), [4]UEDCL (Uganda Electricity Distribution Company Limited), [5]KIS (Kalangala Infrastructural Services LTD); [6]BECS (Bundibugyo Energy Cooperative Society), [7]PACMECS (Pader-Abim Community Multi-Purpose Electric Cooperative Society), [8]KRECS (Kyegegwa Rural Electricity Cooperative Society)

The leadership over the electric cooperatives follows a top-to-bottom model. REA plans the investment and leases the electricity lines to the distribution concessionaires, including the cooperatives, to operate under specified concession arrangements (World Bank, 2015). However, these decisions are contingent upon the proposals submitted by electricity cooperatives, as they possess a better understanding of the local conditions. As a result, power lines are constructed under the supervision of REA only after receiving recommendations from electric cooperatives regarding the communities that should be connected. Once the power lines are commissioned, REA transfers the 'ownership' of the infrastructure to the cooperatives, who assume full responsibility for its maintenance. The tasks of power distribution, household connections, electricity sales, and line upkeep are delegated to electric cooperatives (Lo & Kibalya, 2023).

The concession arrangements also have targets that typically state annual performance targets with attached bonuses and penalties. The targets also include the percentage of fee collection for connections, O&M expense reduction, percentage of damaged transformers repaired, the ratio of connected consumers to applications, length of time to wait for connection, and timeliness in the complaint response (World Bank, 2015). In addition to the lease contract provided by REA, the cooperatives are also bound by two other licenses for the sale and distribution of electricity by the ERA (World Bank, 2015). As part of the regulations, the ERA determines the electricity prices. The cooperatives procure power from the grid and sell it to end users at rates determined by the ERA. This implies that the cooperatives lack the authority to determine the final tariffs per unit of electricity, instead adhering to the tariffs established by the government.

Whereas steps have been taken to minimise the risk for cooperatives and other distribution concessionaires to their obligation to pay the lease and avoid conditions for default or termination (which include overly poor service and corruption or misallocation of funds), the electric cooperatives in Uganda have faced detrimental operational challenges. In their case study research on two electric cooperatives, PACMECS and KRECS in Uganda, Lo & Kibalya, 2023, uncovered some of the main barriers faced by the cooperatives for PACMECS, vandalism and illegal connections to electricity created safety issues and financial stress for the cooperative (Lo & Kibalya, 2023). The cooperative has been dissolved, and the region electrification has been transferred to UEDCL. Even though the services provided by PACMECS were pre-paid, the cooperatives heads shared that delayed reimbursement by the government for parts of the network upkeep left the company indebted to the tune of two billion Uganda shillings (UBC Television Uganda, 2023).

The challenges experienced by KRECS were similar in that they related to the slow response of REA in implementing the cooperative's recommendations, resulting in communities not receiving electricity despite being deemed ready for power lines. Also, the power network experiences frequent breakdowns due to heavy rains and ageing facilities, necessitating regular replacements and making maintenance costly for the cooperatives. The halting of the distribution of free electricity meters increased the backlog of new connections because rural residents cannot afford the fee, typically 715,000 Ush (Lo & Kibalya, 2023).

In addition to the challenges posed by vandalism and insufficient government support, the revenue streams vital to the cooperatives have also been significantly compromised. The prevailing "hand to mouth" economic conditions have made it highly challenging for many rural populations to contemplate the utilisation of electricity. Electricity is perceived as a lifestyle luxury for many, making it even more improbable for them to cover connection fees or consider cooperative membership costs. Moreover, the tariff structure established by the ERA is contingent on the distributor's number of connections. This has resulted in disproportionately higher tariff rates in rural areas, surpassing those of more urban counterparts. For instance, in the second quarter of 2022, the domestic tariff for KRECS stood at UGX. 750.8, in stark contrast to the UGX. 747.5 tariff of UMEME (ERA, n.d.) further accentuates the disparity. Unfortunately, these challenges have proven detrimental for cooperatives, with only KRECS currently operational and the other two since being taken over by UEDCL (Reporter, 2021).

3.3 Selection of Technologies to be Assessed

The country has curated a number of policies and legal frameworks for different generation sources, with the overarching policy being the Energy Policy for Uganda, 2002. Therefore, first, we look at some laws from which a list of available resources and technologies can be derived and a general idea of the associated objectives obtained. This section also answers sub-question two of this research.

Table 3 Summary of Uganda's Policy and Legal Framework (MEMD, 2023)

Elements	GoU Response
Enabling policies	• Energy Policy of 2002 • Oil and Gas Policy 2008 • Renewable Energy Policy 2007 • Electricity Connections Policy (2018) • Gender Policy (2007) • Climate Change Policy (2015) • Environment and Social Safeguards Policy (2018)
Enabling laws/legislation	• The Electricity (Amendment) Act 2022 • The Petroleum Supply Act 2003 • Atomic Energy Act 2008 • The Petroleum (Refining, Conversion, Transmission and Midstream Storage) Act, 2013 • The Petroleum (Exploration, Development and Production) Act, 2013 • Biofuels Act 2018 • The National Environment Act, 2019
Functional Feed-in-Tariffs	ERA regularly publishes a standardized Power Purchase Agreement (PPA) with feed-in-tariffs
Functional Energy Regulator	ERA, Atomic Energy Council, Petroleum Authority of Uganda
Regional Energy Infrastructure (Power Pools)	East African Power Pool

Energy Policy for Uganda, 2002, is the leading energy policy for the country. The policy's main goal is to 'meet the energy needs of Uganda's population for social and economic development in an environmentally sustainable manner.'

The policy covers issues of energy subsectors, namely, power, petroleum, renewable energy sources and atomic energy, with the below-listed objectives;

- To establish the availability, potential and demand of the various energy resources in the country.
- To increase access to modern, affordable and reliable energy services as a contribution to poverty eradication.

- To improve energy governance and administration.
- To stimulate economic development.
- To manage energy-related environmental impacts.
- To increase the role of the private sector in the power sector operations and future development.

These energy objectives have been further categorised within the policy for the demand and supply sides, and strategies have been developed for both categories. Strategies described for the demand side, which includes Households, Industries, Transport and Agriculture, are the provision of affordable energy, improved energy access, improvement in the efficiency of energy technologies, sensitisation of end-users and the transition to cleaner energy.

For the supply side, the principal goal is to provide adequate and reliable energy efficiently. The strategies include increasing competition to provide marginal cost energy and add capital into the sector, incentivising the private sector investments, increasing electricity capacity, providing proper regulation and implementing the rural electrification strategy and plan. For the petroleum sub-sector, the main objectives stipulated in the policy include;

- Upstream: To establish the country's petroleum potential and promote exploitation.
- Downstream: To ensure an adequate, reliable and affordable supply of quality petroleum products for all sectors of the economy at internationally competitive and fair prices within appropriate health, safety and environmental standards

Currently, plans are underway to extract the country's petroleum resources in Western Uganda with the target of the first oil output in 2025. The country's crude reserves are estimated at 6.5 billion barrels, of which 1.4 billion barrels are economically recoverable. The existing oilfields are co-owned by two International Oil Companies (IOCs), Chinese National Oil Company (CNOOC) and TotalEnergies, and state-run Uganda National Oil Company (UNOC) (PAU, 2023). However, despite the substantial economic boost the scale of the project has to offer, it is met with resistance from both local and international environmental activists who fear the effect a spill could have on the agricultural livelihoods and biodiversity in the vicinity of the oil fields [(Athumani, 2023), (Independent, 2023)

The policy has recently been amended to the **Energy Policy of Uganda 2023** (pending public release) to continue its predecessor's efforts. The objectives of the new policy place specific emphasis on the continued development of electricity generation, transmission and distribution infrastructure, adoption and utilisation of energy-efficiency practices, but most notably, continued development of the emerging energy resources nuclear, geothermal, wind and even hydrogen.

The Renewable Energy Policy for Uganda, 2007: The overall goal of the policy was to increase the use of modern renewable energy from 4% in 2007 to 61% of the total energy consumption by 2017. The fundamental principles of the policy not only pertain to renewable energy development in terms of efficiency, access and reliability, among others but also include fostering the gender dimension, stakeholder participation and people experiencing poverty in the implementation of renewable energy projects.

Aside from developing the legal and institutional framework needed to promote renewable energy investments, the policy aimed at establishing appropriate financing and fiscal policies, promoting research and development, international cooperation, and technology transfer, ensuring efficient utilisation of biomass energy, fostering sustainable production and utilisation of biofuels, and encourage the conversion of municipal and industrial waste to energy. Additionally, the policy focuses on promoting power generation from a diverse range of renewable sources, including mini-hydro power schemes, biomass, cogeneration, wind, solar, geothermal, and peat, with potential consideration of nuclear power in the long term.

The means of remuneration for private power produced is a feed-in-tariff (FiT) scheme introduced in 2007 (Mokveld & Von Eije, 2018). Moreover, in order to further pursue the development of low-carbon technologies, the Global Energy Transfer Feed-in-tariff (GETFiT), promoted by private developers, was rolled out to provide financing mechanisms for small-scale renewable energy generation projects [(ERA, 2018), (Mokveld & Von Eije, 2018)].

The Atomic Energy Act of 2008 legislation was designed to govern the peaceful utilisation of ionising radiation. Its primary objectives include establishing the Atomic Energy Council, a corporate body charged with issuing authorisations and granting exemptions for the possession and use of radiation sources and carrying out inspections, amongst other things. The policy also aims to ensure the safety and protection of individuals, society, and the environment from the hazards associated with ionising radiation, regulate the production and use of radiation sources, manage radioactive waste, promote and develop nuclear energy for peaceful applications, adhere to international safety requirements for ionising radiation, radiation protection, and security of radioactive sources. The Act also establishes a Radiological Emergency Response Committee and a Nuclear Energy Unit.

The country also announced in March 2023 its plans to start 2000MW of nuclear power generation to diversify its energy mix further and accelerate its energy transition. The plans include the installation of a 1000 MW powerplant in Buyende District by 2031 (Reuters, 2023) in partnership with an international investor, China National Nuclear Corporation (Kyeyune, 2023).

3.3.1 Criteria and Evaluation of the generation resources and technology

From the above analysis, we derive the following broad objectives reflecting the country's aspiration to enhance energy access, promote sustainability, and stimulate economic growth through diversifying its energy mix.

1. Meet energy needs sustainably: Ensure the availability and potential of energy resources while meeting the population's energy needs for social and economic development in an environmentally sustainable manner.
2. Increase energy access and affordability: Enhance access to modern, affordable, and reliable energy services to alleviate poverty and promote development.
3. Improve energy governance and administration: Enhance governance and administration of the energy sector to ensure effective management and regulation.
4. Encourage private sector participation: Increase the involvement of the private sector in power sector operations and future development to foster competition and attract investments.
5. Promote renewable energy and low carbon technologies: Foster the development and utilisation of modern renewable energy sources, as well as set in place favourable financial mechanisms to support the projects
6. Ensure energy efficiency: Improve the efficiency of energy technologies and promote the transition to cleaner energy options.

These objectives also serve to define a set of criteria for the evaluation of the generation technologies. Factors such as low-carbon emission, sustainability, technology maturity, reduction in energy prices, social acceptance, and political backing emerge as important themes in the policies above. These have also been covered in other literature such as Bhandari et al. (2021).

3.3.1.1 Maturity of Technology

The life cycle of any technology can be broken down into three phases: growth, maturity, and decline, as shown in the S-curve depicted below. The maturity phases of any technology can be evaluated by a definition of development time and commercialisation capacity, efforts made in (research and development) R&D outside of the laboratory, and the advantages of technology rivalry (Filho et al., 2021). For energy generation technologies, the technology maturity directly affects the expected energy output, reliability and cost reduction of the energy source. High levels of commercialisation also imply an ease in adopting technology without further research and development.

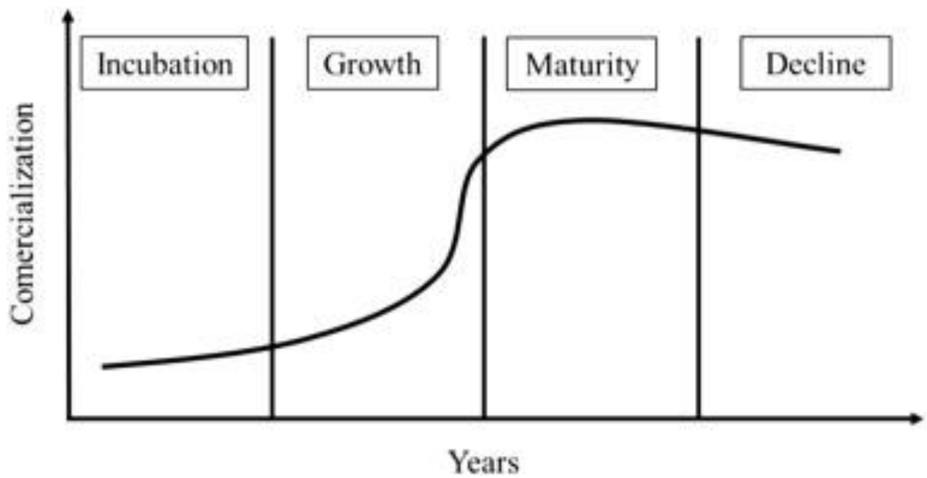

Figure 4 Typical S curve of the technological maturity process (Filho et al., 2021)

3.3.1.2 Sustainability

Sustainability regarding energy generation is a multi-faceted concept. Though often used interchangeably with renewable energy, the overlap lies in that sustainable energy resources are most often renewable. Renewable energy is defined by the time it takes to replenish the primary energy resource compared to the rate at which the energy is used. In contrast, sustainable energy is derived from resources that can maintain current operations without jeopardising future generations' energy needs or the climate (Wigley, 2023). Sustainability considers factors affecting energy generation, distribution and consumption, such as geography, economics, availability and politics (Wigley, 2023). For example, whereas energy sources such as solar and wind harnessed via PV systems and wind turbines may be considered renewable forms of energy, the rarity of some of the minerals required to manufacture the technologies affects the sustainability of their use (Huber & Steininger, 2022).

3.3.1.3 Reduction in energy prices

Under the previous discussion on rural electrification, many economic constraints were mentioned relating to the unfavourable economics: the high investment costs associated with grid expansion and infrastructure development vs. expected low returns from serving poorer populations. The affordability dimension, however, does not only characterise the profitability in energy markets; producing energy services at the lowest cost is observed through competition and subsidisation (Wabukala et al., 2022). Among the solutions discussed in the RESP II policy and literature is using alternate generation and distribution infrastructure forms to reduce the cost gap. This will be discussed in more detail in the next section.

3.3.1.4 Political support and social acceptance

These two points are deliberately juxtaposed for intriguing discussion, as they are often seen in the literature as complementary yet conflicting forces working towards a shared objective. Political power or *Energopolitics* is understood as the operations of power to leverage modern energy sources' transformational capacity (Burke & Stephens, 2018). Political support or will for different energy developments is exercised through the institutionalisation of policies to achieve a set agenda, such as the previous section's discussion on Uganda's energy policies and agenda for universal electrification as well as comparable strategies with other countries like Kenya, India and Nepal. Nevertheless, for the most part, policy initiatives are ineffectual with the urgency and scale of what is required, whether regarding the slow transition to sustainable energy systems (Jefferson, 2008) or slow electrification rates (Trotter & Maconachie, 2018). Furthermore, on the other end of that spectrum is the aspect of acceptability, which relates to environmental and socio-economic values that shape not only the extraction and production but also the consumption of energy resources (Wabukala et al., 2022). In other words, you can take the cow to the well but not make it drink. These two go hand in hand. Therefore, it is becoming more imperative that the involvement of people at the grassroots is harnessed and sound commercial and technical criteria are applied (Jefferson, 2008).

Stakeholders were asked to rank the above criteria and share insights based on their line of work for their assigned ordering. Figure 4 below shows the results of this survey.

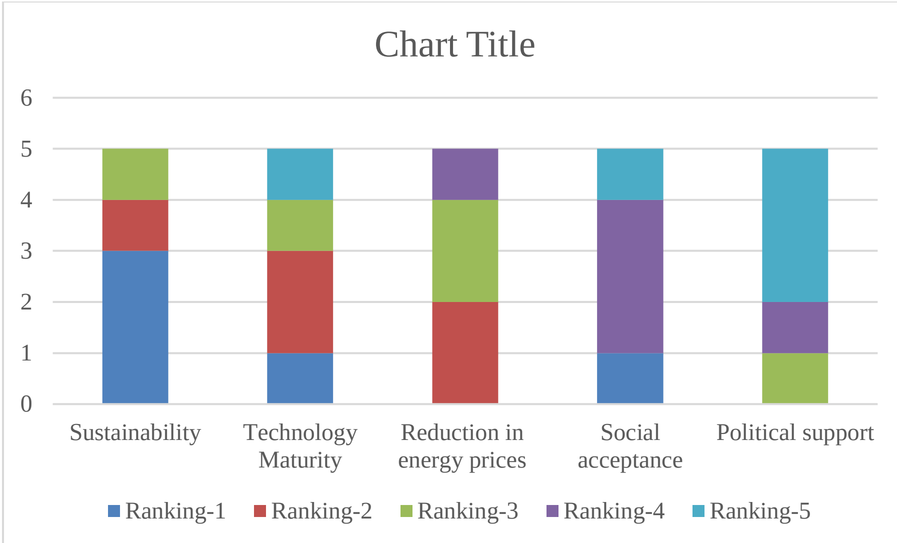

Figure 5 Generation Technologies criteria

From the above responses, we can see that sustainability, technology maturity and reduction in energy prices hold the top three most significant weights, respectively, in considering the energy sources and technologies to be exploited for rural electrification. Amongst the respondents, sustainability was looked at mainly from the angle of reproducibility of the resources, whereas price reduction would be determined first and foremost from the upfront cost of the energy technologies; finally, technology maturity was seen to have a direct bearing on expected energy output. The expectation held by most respondents is that following the adherence to the first three criteria, social acceptance and political will would follow. However, it may be interesting to note that the single respondent that ranked social acceptance first also ranked political will number four; as their work is more directly related to the end user, this may indicate appreciation for the implication of social dynamics on energy projects and initiatives. They argue that initiatives such as this are only as good as the adoption rates of the beneficiaries for whom they are intended and insist that political will is essential for their actualisation, especially regarding funding and sensitisation.

3.3.2 Generation resources and technology alternatives

Following the discussion on criteria, we now look at the generation resources and technologies to be considered for Uganda's energy mix. Table 4 below shows the list of generation resources the sector has set out to exploit through its policies. The proceeding discussion and evaluation of these technologies is thus based on the abovementioned criteria.

Table 4: Generation Resources and Technologies

Resource	Potential	Vision 2040 (MW)	Technology	Source
Large Hydro	2000 MW along the R.Nile	4500	Hydro-power dam Run-of-river	(REP, 2007)
Mini-hydro	200 MW			(REP, 2007)
Oil	1.4 billion bbl. of crude oil (Production: 60,000 bbl./d)	4300	Oil-based/ Thermal power plants	(PAU, 2023)
Nuclear	64,000km^2 / 105,000t U_3O_8	24000	Nuclear power plant	(NEA & IAEA, n.d.)
Solar	200 MW An insolation of 11.98 h/d, average radiation of 5. kWh/m^2	5000	Solar photovoltaic system	(ERA, 2020), (REP, 2007)
Biomass	A potential of 407MW from Agricultural residue	1700	Co-generation	(REP, 2007)
Geothermal	450 MW	1500	Geothermal power station	(REP, 2007)
Peat	800 MW	800	Peat-fired power plant	(REP, 2007)

The total installed capacity of the energy sources has yet to be realised and stands at approximately 1270 MW out of the target 41,800 MW. The current generation capacity is derived from four energy sources: Hydro (1024MW), Thermal (100 MW), Cogeneration (64 MW), and Grid-connected Solar (60 MW) (Wabukala et al., 2022). However, a forecasted availability of these resources does not automatically translate to energy accessibility and security, especially for rural populations. Regarding energy security, electricity must be available at the right time, affordable, and reliable. Whereas for energy accessibility, authors Wabukala et al. (2022) note that it relates to two important components: the spatial distribution of energy resources and the physical infrastructure that distributes the energy produced to the final user.

The spatial distribution of the energy resources and the physical structure comprise the on-grid and off-grid distribution strategies for the RESP II mentioned in the previous section.

On-grid systems follow the classic energy supply chain in which primary energy is harvested remotely and may be transformed (in this case, into electricity) before it is transported to where it is finally used. These systems benefit from substantial economies of scale to reimburse the associated high capital investment, which, as previously mentioned, is a challenge with rural electrification. Electricity from all the large-scale generation sources (i.e., large-hydro, thermal, co-generation, large solar farms, geothermal and nuclear) are currently supplied or in plans to be supplied to the national grid and, in the proceeding analysis, will be categorised as a single technology option for rural electrification. The remainder of the technologies present a more distributed category and will be considered as options for off-grid distribution.

Off-grid, also commonly referred to as mini, micro or distributed grids, are independent electricity delivery systems in which the power is produced near the point of consumption. The mini-grid production system consists of energy generation technologies, inverters, a management system and sometimes storage (such as batteries) (USAID, n.d.). The production system determines the mini-grid's overall capacity to provide electricity to end users. More commonly, the use of distributed systems is suggested for rural electrification [(Bonamini et al., 2019), (Pandiyan et al., 2022), (Kirubi et al., 2009)]. They are often presented as solutions to overcome challenges related to the economic feasibility of rural electrification as they are easier to implement in areas far from the national grid and, depending on the technology, can be gradually scaled up with increasing demand.

3.3.2.1 Solar PV mini-grids

Solar PV mini-grid systems are the preferred technology for off-grid rural electrification, as noted in the RESP II and by the consulted stakeholders. Advancements in photovoltaic (PV) technologies and cost reductions have been important drivers for expanding the mini-grid sector worldwide. Another important factor for adopting PV mini-grids is the availability of sufficient solar irradiance across the country. The daily specific photovoltaic power output ranges from 3.58 – 4.92 kWh/kWp and direct normal radiation between 2.58 – 5.60kW/m^2 daily (Solargis). The high potential has more recently encouraged funding and investments; for example, the non-refundable grant by Germany's state development agency (GIZ) and the European Union to Winch Energies to install mini-grids across 25 villages in northern Uganda (Mwirigi, 2021). A third main benefit of solar PV is its modularity and scalability (Bhagavathy & Pillai, 2018). This means they are easily transportable even to the most remote locations, and their installation can be scaled up with increasing demand.

Figure 6 Winch Energy, one of the IPPs involved in solar mini-grid projects in Uganda (Bungane, 2021)

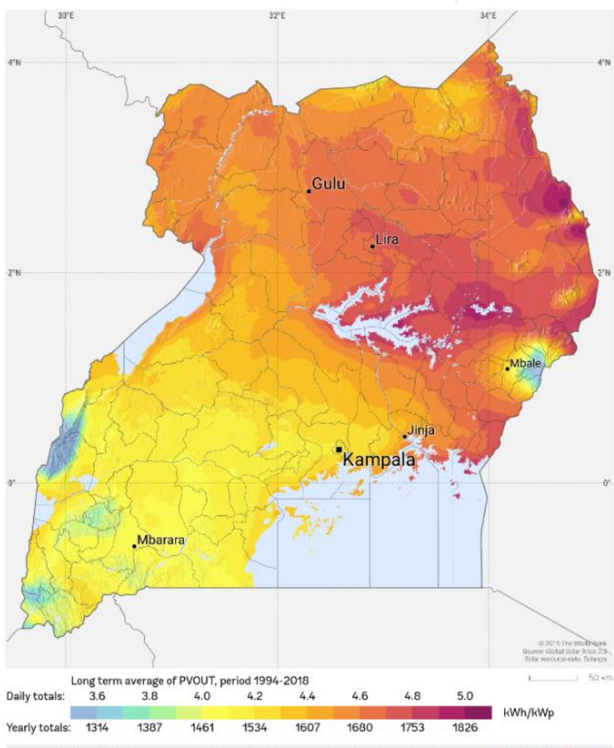

Figure 7 Photovoltaic power potential (Solargis)

Complementary to solar mini-grids is the use of solar home systems. The technology is the same as solar PV grids, minus any form of distribution from a single home and is intended for individual use. As part of its program of activities for rural electrification, REA intended mainly to substitute fossil fuel-based lighting, like kerosene lamps, with LED/CFL light systems powered by batteries charged either by PV systems or other mechanical systems such as a hand crank charger. These systems are also commonly used for phone charging and powering other small home devices. One minor setback was observed with the adoption of solar home systems: they do not follow the common assumption that their adoption leads to higher home incomes; in other words, they contribute little towards short-term 'productive uses' for rural communities (Stojanovski et al., 2017).

Table 5: Self-reported utility of a SHS (Stojanovski et al., 2017).

"My SHS is most useful for":	**Uganda (N = 149)**	Kenya **(N = 79)**	**"My SHS is most useful for":**
Comfort/improving the house	91%	91%	Comfort/improving the house
Saving money	2%	5%	Saving money
Earning more money	2%	0%	Earning more money
Social status/respect	1%	1%	Social status/respect
All of the above	4%	3%	All of the above

Another setback is that special consideration needs to be taken before a home can purchase any additional devices. However, Stojanovski et al. (2017) suggest that adopting a plug-and-play SHS-compatible market for electronics independent of the solar companies could be vital to unlocking the benefits of broader electrification through SHS market growth.

Even with the envisioned benefits of solar PV mini-grids, several factors need to be deliberated upon for their successful adoption. A more obvious point is that solar is an intermittent energy source, meaning that electricity is only available when the sun is available for these systems. Therefore, storage, a pricy investment, becomes an imminent requirement to enhance energy supply and security. To put this into perspective, purchasing and operating a battery can sometimes cost more than operating a diesel generator continuously, especially when operators are unlikely to maintain and use the battery correctly (USAID, n.d.). The increased investment cost, in turn, translates to higher tariffs for the end users. Waste management of the products from these off-grid systems should also be considered, especially with their large-scale rollout plans. Solar PV and most other off-grid systems also contain precious, critical and toxic materials, which could have significant socioeconomic and environmental implications, such as the depletion of finite critical materials and the discharge of toxic pollutants (Kinally et al., 2022).

3.3.2.2 Small and medium-scale hydropower

Hydro resources in Uganda are abundant, with the country lying predominantly within the Nile basin, characterised by eight main drainage basins, including prominent water bodies like Lake Victoria, Lake Kyoga, and Lake Albert. Despite their relatively small contribution to the total Nile flow, these catchment basins hold significant water resource potential within the country. Lake Victoria, the largest lake in Africa, and the River Nile, its only outflow, form the foundation for existing and future major hydroelectric projects in Uganda (a total estimate of 2000MW). Small and medium-scale hydropower sites are not located on the Nile. These sites are majorly located in the Western and Eastern regions of the country, which are hilly and mountainous. Studies have approximated a total of 210 MW electrical capacity from 59 sites with the potential to be used for distributed grids and supply to the national grid (Fashina et al., 2018).

Figure 8 SHP Rwimi, Uganda (HYPOSO, n.d.)

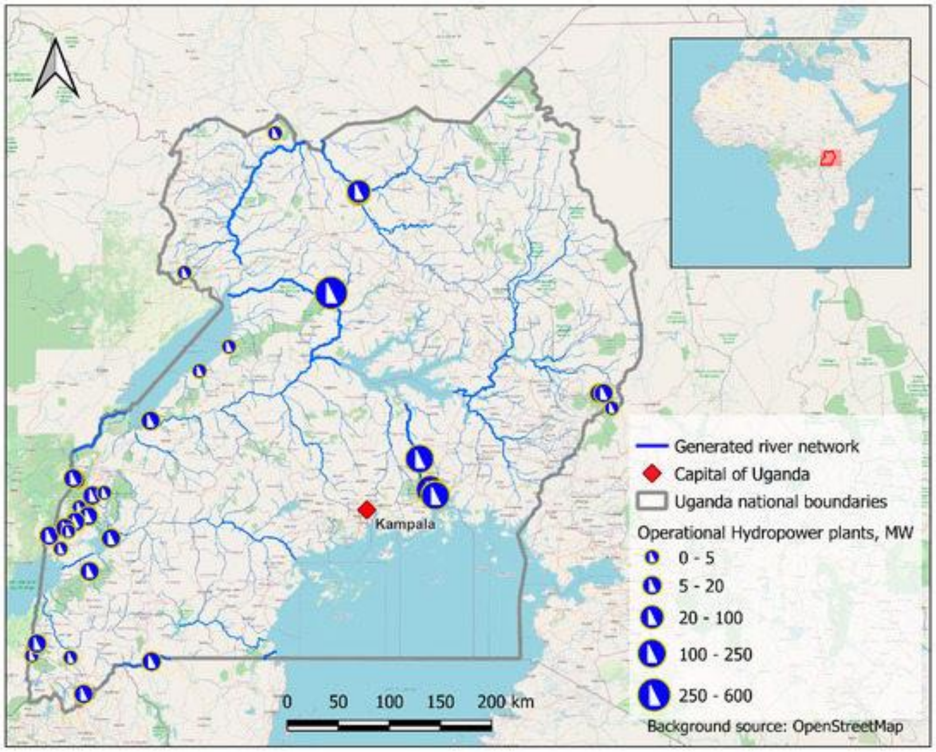

Figure 9 Uganda's river network and hydropower plants under operation (Punys et al., 2023)

More specifically, regarding their prospects for rural electrification, hydro-power projects have less storage requirement (and can themselves be a means of energy storage), and their scale could allow them to benefit from larger economies of scale, making tariff costs more affordable. However, the site specificity reduces the flexibility of their deployment as dams can only be constructed in parts of water bodies with sufficient elevation and run-off (Punys et al., 2023).

Some challenges associated with hydropower exist in the planning phases of the projects due to the high upfront costs and a financing gap that cannot be solely bridged by public sector funding, a lack of skilled manpower to operate and manage the running of power stations, low levels of Research and Development, and tedious land acquisition process among others. Additionally, social and environmental considerations must be taken as dam construction has been known to divert waterways, cause floods and impede fish migrations (Project Drawdown, 2023).

3.3.2.3 Biomass

The country's bioenergy is supplied through biomass and biogas, accounting for 94% of the country's total energy supply (GIZ, 2022). Most biomass in the form of wood and charcoal and the production of biogas from small-scale biogas installations are used directly for cooking. In the renewable energy policy (REP, 2007), other applications for biomass have been noted, including electricity generation, fuel for vehicles and furnace oil substitution. Crop residues were cited as playing a significant role in power generation. Whereas the resource is not strongly exploited, there has been headway in the sugar industry, where excess bagasse is used for electricity generation using Combined Heat and Power systems (with an estimated potential of 1650 MW (GIZ, 2022).

Table 6: Energy Production from Agro-residues (REP, 2007)

Biomass Type	**Annual Production ('000 tons/yr)**	**MW e average**	**Biomass Type**
Bagasse	590		Bagasse
Bagasse Surplus (available immediately)	3×25-50	67	Bagasse Surplus (available immediately)
Rice Husks	25-30	16	Rice Husks
Rice straw	45-55	30	Rice straw
Sunflower hulls Cotton seed hulls	17	20	Sunflower hulls Cotton seed hulls
Tobacco dust	2-4	2	Tobacco dust
Maize cobs	234	139	Maize cobs
Coffee husks	160	95	Coffee husks
Groundnut shells	63	37	Groundnut shells
	Total	**407**	

Regarding its feasibility for rural electrification, some significant challenges hinder its utilisation, as Mandelli et al. (2016) recorded in their literature review of off-grid systems for rural electrification. These are listed below.

1. **Infeasible Plant Size:** Economic feasibility for electricity production in rural areas typically requires a minimum plant size of 10-100 kW, which fits the micro-grid scale but not the stand-alone scale. The steam cycle technology, suitable for grid-

connected generation plants, is available for loads higher than 5 MW, posing challenges for smaller rural setups.

2. **Complex Supply Chain:** The sustainable use of bioenergy for power generation in rural areas faces difficulties due to the complexity of the supply chain. This involves developing and managing intricate biomass supply systems and implementing specific measures to reduce pollutant emissions. Addressing these complexities requires local capacity and detailed local-level analysis.
3. **"Flavor of the Year" Phenomenon:** The bioenergy arena experiences a trend of shifting focus from one biomass resource to another, leading to a lack of consistent policies and forethought. The rush to develop new resources and technologies without robust institutional structures hinders the smooth progress of bioenergy projects in many African and Asian countries, which is essential for rural development.

3.3.2.4 Diesel generator

Diesel generators are the most conventional technology for rural electrification (Mandelli et al., 2016). The diesel-generator sets are mostly preferred due to their high convenience levels in terms of low capital cost, simplicity of the technology, no civil work preparation required, short installation time, supply flexibility from a few hundred watts and more, and ease of use for more inaccessible areas (Lahimer et al., 2013). These systems have also been studied extensively in the literature for use in hybrid micro-grid systems to overcome the need for batteries by coupling diesel generators to renewable-based systems while reducing the storage system size [(Mandelli et al., 2016), (Cartland et al., 2023), (Lahimer et al., 2013)].

Diesel-fueled generators and, more generally, fossil-fueled generation are less encouraged for rural electrification due to the economic and environmental drawbacks. The high tariff costs are primarily associated with high diesel fuel costs, transportation and storage of fuel, especially for highly remote places, and frequent maintenance because of the several moving parts. Additionally, burning fossil fuels leads to the emission of greenhouse gases, which harm the environment. However, for fossil fuel power generation, it will be interesting to observe whether the country’s current oil exploits might negate the environmental impacts, as the country may use more readily and easily available resources.

3.3.2.5 Grid extension

Grid extension refers to grid connections to households and institutions/SMEs previously not connected to the regional/national grid. The assumption is that these users were previously supplied by a high-carbon intensive mini-grid, stand-alone generators, or fuel-based lighting systems. The switch to grid-supplied electricity has a number of positive environmental impacts as well, including reduced use of fossil fuels, replacement of dry cell use, and reduced inefficient use of biomass (Gaul et al., 2019). Grid extension generally has high initial costs for the expansion of transmission lines but low costs per unit of electricity; its relatively high service levels also allow for an array of electric appliances (Barnes, 2011).

According to the RESP II, on-grid electricity service expansion includes reconfiguring the rural electrification sector into thirteen appropriately demand-sized and commercially scaled service territories with permanent service providers (including the cooperatives). These private service providers are to be duly licensed to perform the expansion programs and be responsible for ensuring that service is offered to all eligible applicants within the service territory according to service territory expansion plans.

In theory, supply from the main grid is sufficient to meet the current demand for the country. The country's installed capacity of 1269MW against a peak load of 758 MW may translate into a widespread belief that Uganda has an excess supply of electricity, leading to the conclusion that the country is 'electricity secure' in terms of availability; however, the surplus only exists because 42% of the population has access to grid electricity (Wabukala et al., 2022). The country also continues to suffer from perennial power outages due to a multitude of factors, including system breakdowns due to natural hazards, an ageing infrastructure, electricity thefts and vandalism of transmission and distribution infrastructure (Wabukala et al., 2022). In addition, for rural areas, connection costs are a severe barrier to poor households; even with subsidies like the 100% subsidised free 1-pole connection, the costs of in-house wiring are an inhabitant (Gaul et al., 2019). Even though the use of grid access leads to increased use of electrical lighting and larger appliances compared to off-grid solar access, the difference is limited for rural households and even businesses, which might be suppressed by the low reliability of grid power and limited business capacity (Gaul et al., 2019).

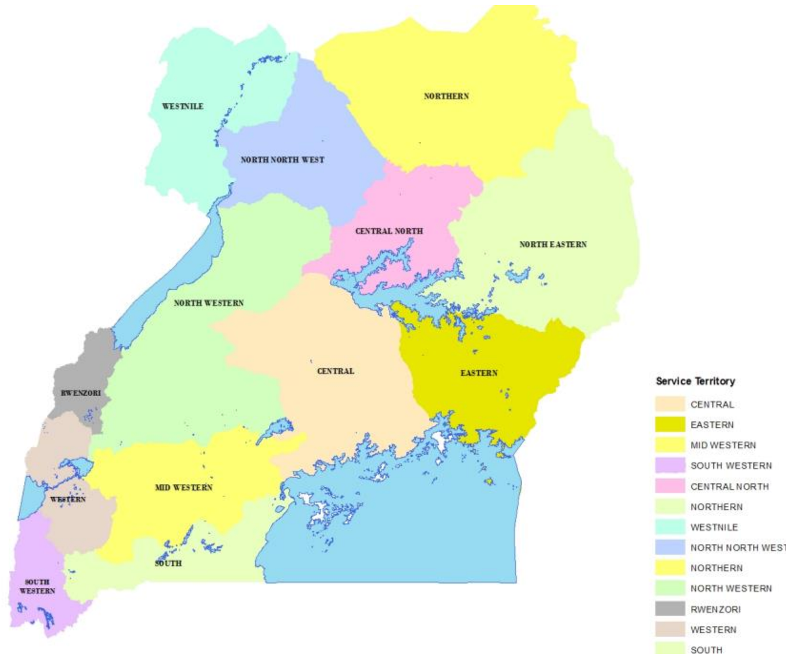

Figure 10 Proposed Service Territories (RESP II)

The stakeholders were also asked to rank the above-discussed generation sources for rural electrification and consider the previously mentioned criteria. Their responses below show a high correlation to the discussion already for each generation source and technology.

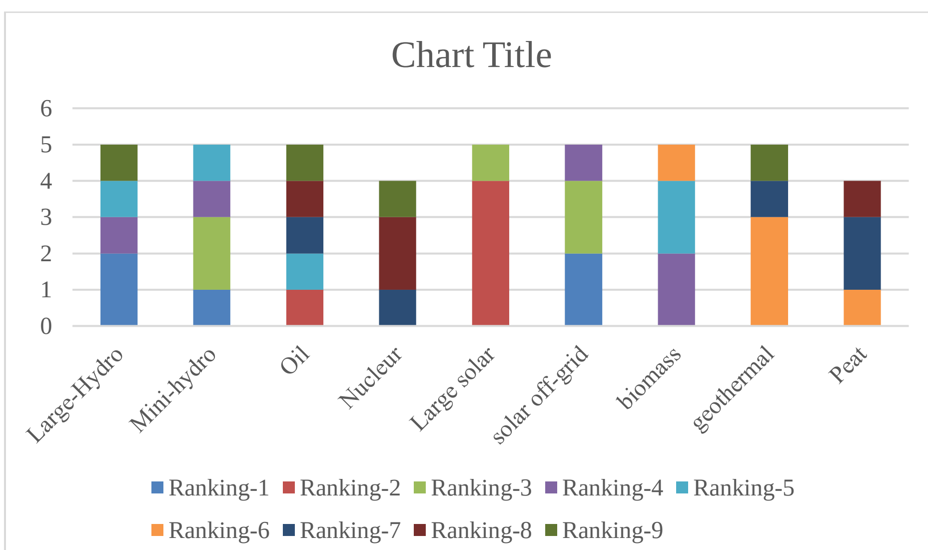

Figure 11: Ranking for Generation Resources and technologies

Of the large-scale generation technologies, hydro-power and solar are preferred owing to the enormous potential capacity to be developed; however, for rural electrification endeavours, the respondents noted the need for grid densification, especially for the large-size investment to make sense.

Large-scale solar is preferred to off-grid solar because of the possibility of production of power quality that can be supplied to the grid and its ability to take on motorised loads in addition to relatively light loads, which is not usually the case for smaller-scale solar. Nevertheless, off-grid solar using micro/mini-grids is still a notable contender for rural electrification owing to the main points already cited, i.e., its modularity and availability across the country. The point previously argued under the 'Grid extension' section is that electricity use in rural areas is still basic. It is used mainly for lighting and has yet to necessitate a more complex grid. One respondent also mentioned that mini-hydro has the potential to provide overall best efficiencies. However, it is indeed affected by the limited geographical locations, as potential streams need adequate flow and head required for electricity generation.

Biomass, Oil, Nuclear, Peat and Geothermal are ranked lowly by almost all survey participants for a number of reasons. Given that most participants viewed sustainability as an important criterion, resources like peat and oil were 'disqualified' due to their non-renewable nature and emissions of greenhouse gases. However, one participant pointed out that fossil-fuel plants should not be cancelled altogether yet, citing examples of their contributions to electrification efforts in the north-western part of the country where WENRECo is supplying 1.5MW of electricity using an HFO-run powerplant (Mbabazi, 2023) and KIS, which uses a 1.6 MW solar-diesel hybrid system to supply the islands of Kalangala (*KIS*, n.d.). The primary limitations highlighted with biomass were its poor scalability and efficiency and the unsustainable production of biomass feedstock outside the sugar industry. Geothermal and Nuclear are relatively new territories still largely underdeveloped, which makes their realisation less plausible in the short term.

Chapter Conclusion

In this chapter, we have discussed criteria based on policy and stakeholder inputs by which the different generation resources and technologies are assessed to determine the country's energy mix. Based on this, we derive the list below from the most suitable to the least for the shorter-term realisation of rural electrification.

1. Solar PV mini-grids (at mini- and micro-scale)
2. Small-hydro mini-grids
3. Grid-extension
4. Hybrid Diesel Generator mini-grids
5. Biomass

The proceeding chapter is on the development and execution of a gaming session with stakeholders. Some of the technologies derived from this chapter are included in the game. The results from this chapter provide a basis for comparison with the results from the game, the aim of which is to see if the criteria determined as most critical are still upheld when other dynamics within the system come into play.

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4 Developing the serious game

4.1 Serious Games for Energy

Numerous serious games designed for various energy applications have been discussed in literature and online sources. Scientific reviews of energy-related serious games cover different areas, such as sustainability education (Stanitsas et al., 2019), the development of energy portfolios (McGookin et al., 2021), energy transitions (Wagner & Gałuszka, 2020), and gamification within domestic energy consumption (Johnson et al., 2017). Websites like Games4sustainability.org and Gamesforchange.org hold a collection of these games, mainly digital ones, alongside a few board games. Researchers have also employed serious games for research, often making location-specific adaptations. They use maps and spatial strategies to map regional energy demand and production in their game development [(Nabielek et al., 2018); (Thomas et al., 2018)]. The increasing number of references suggests the practicability of serious games for tackling complex energy challenges.

For this research, a pre-existing game will mimic decision-making about developing a rural energy system in Uganda. An already existing game is being considered instead of developing a custom game due to the limited time available to conduct the study. Nonetheless, adopting an existing intervention can yield significant efficiency gains over developing a new intervention – with effectiveness contingent on the context into which it is evaluated. For one, it offers efficiency in terms of faster development and lower costs. Secondly, existing institutions have demonstrated their effectiveness. Even though games may be based within disparate societal contexts, Persuading those resistant to change by pointing to these results is easier than arguing about completely original ideas (Mamadouh et al., 2002). Therefore, to get the most out of the selected game, particular attention must be paid to its structure.

Prerequisites of the game include its availability, customizability, and preference has been given to the use of a board game. Preference was given to board games to negate the need for more costly resources such as computers and the Internet. Also, using a board game and the workshop setting should facilitate more collaboration and discussion between the players.

In terms of customizability, the game's context needs to be modified to the Ugandan rural context. This can be visualised by looking back at the three perspectives; in order for the game to help provide analysis through the three perspectives (techno-economic, socio-technical and political), its structure should include the dynamics that represent the perspectives, i.e., energy flows and markets, energy technologies, and energy-related policies. These three systems can be presented in the game as one or more variables listed from the framework by Cherp et al. (2018) in Table 7 below.

Table 7 Top-level and selected second-level variables in the three perspectives framework (Cherp et al., 2018)

Techno-economic	**Socio-technical**	**Political**
Resources	**Innovative systems**	**State goals**
Fossil fuels types, resources, reserves, extraction costs	Presence and structure of national, sectoral and technological innovation systems	Type of state goals (e.g. energy security, access to modern energy, climate change mitigation, technological leadership)
Import and export of fuels and carriers	Performance of innovation systems with respect to their functions, e.g. R&D activities, knowledge stock	Factors affecting state goals, e.g. import dependence and international competition.
Type and potential of renewable resources; cost of relevant technologies		
Demand	**Regimes and Niches**	**Political interests**
- Types and scale of energy uses	- Structure, resources and coordination of incumbent regimes	- Special interests (e.g. industrial lobbies)
- Energy intensity	- Structure and resources of newcomers' niches	- Party ideologies and organised social movements
- Factors driving demand growth and decline, e.g. population and economic growth/decline; industrial restructuring	- Niche-regime interaction, including external support mechanisms	- Voters' preferences
Infrastructure	**Technology diffusion**	**Institutions and capacities**
- Existing infrastructure for extraction, transportation, conversion, and use	- Global maturity of relevant energy technologies	- State capacity, e.g. economic and other resources, political stability
- Age of Infrastructure	- Location on core/periphery of technology	- Institutional arrangements, e.g. varieties of capitalism, party system, government system
- Manufacturing, import and export of equipment	- Possibilities for technology export	- International processes: e.g. policy diffusion, international agreements
- Cost of operation and construction of infrastructure		

The points highlighted in green have been covered in the preceding chapters, while those in yellow are the possible results we could get from the game.

So far, for techno-economic systems, we have looked at the available energy resources available in the country for the production of electricity, i.e., fossil fuel deposits (oil, peat, nuclear) and renewable energy resources (streams of water, sunlight, and biomass) and shared some of the readily available technology for extraction (like solar panels, hydropower dams) and some not yet readily available (e.g. efficient biomass plants and nuclear). We have also noted the growing need to increase energy access, which translates to increased energy demand. In order to supply the energy for the expected demand, the country needs to increase its energy supply and improve its distribution systems, for which we studied two options: centralised distribution (or the main grid) and off-grid or distributed systems. In the previous chapter, we also discussed the cost implications for exploiting different resources, the choice of distribution systems, and the specific complications regarding low demand and affordability in rural areas. These known variables help to form the boundary conditions within the game. We can also see the factors that drive demand growth or decline through the game.

Within the socio-technical realm, the focus is on technological change, more so the diffusion of new technologies. So far, we have noted the extensive use of fossil-fuel-powered generators and biomass in the form of firewood and charcoal in many rural areas for cooking, heating and lighting. We have seen through the different policies and research that the aim is to switch from the unsustainable use of biomass and fossil fuels, which also has negative health implications. However, switching from traditional fuels involves the collaboration between actors, rules and practices to facilitate the change. In the previous chapter, we were able to unlock the actors involved in rural electrification, including the Rural Electrification Agency (REA) distribution companies, rural electric cooperatives, Independent power producers and the rural populations. The policies act as rules to govern the interactions of the actors. Therefore, we need to determine to what extent these rules work, considering the personal interests and circumstances of the actors. What practices result from their interaction with the different technologies, and what external mechanisms can be included to enforce positive practices and adoption?

Finally, from the country's political perspective, we could delineate the country's energy policies and other national policies from which we derived the state's goals. From these and some of the interviews with stakeholders within the sector, we decipher the government's commitment to realising universal access to clean energy for its populations. Even with the various policies, including the overarching Energy Policy, the Renewable Energy Policy, and the different sub-policies for each energy resource, we could pick out general themes relating to sustainability, reliability and accessibility of the country's energy needs. For Uganda's political endeavours, it will be interesting to observe how the country's recent oil exploitation influences its energy policies in the years to come. Fossil-fuel generators are a mature and easily deployable technology, and the country's resource exploitation could significantly reduce its dependence on exports and form an excellent opportunity to boost its economy. To a certain degree, this could also be explored within a game to assess any particular interest or actor lobbies that could affect the state's initial goals.

The concept of the rural electrification institutional arrangements, including cooperatives, is central to this study. We saw in the previous chapter the organisational structure of the electricity sector and the placement of electric cooperatives in this organogram. We have seen the rules by which these actors must play, but we aim to determine what else can be done and what these actors' capacities are within the Ugandan system. The concept of capacity signals that a state is not able to pursue its desires (Cherp et al., 2018). We already covered part of this by examining some of the challenges cooperatives face. However, could the institutions and roles be reorganised to facilitate their work better?

4.2 Serious games on energy: related works

From the previous section, we gather that the selected game should allow for the customisation of the energy technologies, actors, policies and interactions between these actors, similar to the Ugandan context.

The games were sourced from the online platforms Science Direct, Google, and game database websites Games4sustainability.org and Gamesforchange.org. The search yielded four board games that broadly covered the development of an energy portfolio. The selected games were Power!, Energy Transition Game, The Nexus Game, and The World's Future. Below is an overview of each game that led to the final selection.

Power! (Energy.nl, 2023) is a serious game developed by TNO that focuses on the energy transition. The game is designed to educate and engage players in the challenges and opportunities associated with sustainable energy initiatives. It is specifically created for local, sustainable energy cooperatives and partners such as municipalities, network operators, energy suppliers, housing cooperatives, and entrepreneurs. The main objective of Power is to contribute to the transition towards a sustainable energy supply in the Netherlands. The game offers an opportunity for participants to gain valuable insights into the complexities of energy management and learn how to make informed decisions that align with sustainable development goals. Players use the previously mentioned roles to take on various scenarios and tasks related to energy production, distribution, and conservation. To successfully develop and implement sustainable energy solutions, they must navigate various factors, including technological feasibility, financial considerations, and environmental impacts. One of the key features of Power is its emphasis on collaboration and cooperation. Players must collaborate, negotiate, and find common ground to achieve shared goals. However, the location-specific context may be a key deterrent towards the use of the game.

The Nexus Game is an integrated simulation board game that offers participants a distinct chance to understand the water management challenges associated with energy and food production while preserving environmental flows (Nexus Game, 2021). It is a simulation game initially developed to address the complex challenges of transboundary resource management within the Southern African Development Committee (SADC) region. It involves two neighbouring countries, one upstream and the other downstream, facing interconnected energy, food, and water provision issues. Participants take on roles such as the prime minister, water minister, energy minister, or agricultural minister, and their task is to ensure the sustainable delivery of energy, food, and water according to their mandates. The game focuses on promoting sustainable development and fostering positive relationships between countries. It provides insights into effective collaboration mechanisms, collective decision-making, and allocating scarce natural and financial resources.

The Energy Transition Game is a social simulation designed to engage participants in understanding and exploring the complexities of the energy transition, including balancing energy demand, environmental concerns, and economic viability. The game also highlights the importance of public engagement and the role of societal actors in shaping energy policies and driving the transition. The main objective of the Energy Transition Game is to simulate the decision-making processes involved in transitioning from conventional energy sources to renewable and sustainable alternatives. It aims to foster a deeper understanding of the economic, social, and environmental factors influencing the energy transition and facilitate discussions and collaboration among stakeholders.

It is also a role-playing serious game with participants assuming different roles, such as energy producers, policymakers, consumers, or environmental activists, each with their own goals and interests. Throughout the game, they face a range of realistic scenarios and are required to make strategic decisions that affect energy production, consumption, pricing, and environmental impacts. The game is designed to reflect the complexities and interdependencies of the energy system, as well as the trade-offs and dilemmas inherent in the transition process.

The game potentially serves as a valuable tool for policymakers, educators, and stakeholders involved in energy transition initiatives, enabling them to explore different strategies, test policy interventions, and gain insights into the dynamics of the energy system.

World's Future is a social simulation game that explores the complex challenges of global sustainable development related to energy, health, water and food, among others needed for global sustainable development. The play delves into the interconnectedness of social, economic, and environmental systems, focusing on international collaboration. Players who take on high-level leadership roles in different countries must navigate through a range of realistic scenarios, making strategic decisions that have implications for their country and the world. World's Future incorporates many factors and variables, including economic growth, technological advancements, population dynamics, natural resource management, and geopolitical dynamics. The game captures the complexities and trade-offs inherent in addressing global challenges and emphasises the importance of sustainable development principles.

4.2.1 Selection and Adaptation of the Game

The above games were compared on two fronts: using the classifications Savic et al. (2016) suggested for serious games, providing a more general outlay. The classifications include the application area, the goal, the initialisation of the game, the number and type of players, the user interface, the type of simulation model used, the realism of the game progress monitoring and game portability. Secondly, based on the inclusion of the highlighted variables from Table 7.

Table 8 shows the comparison of all four games, and below, the games are discussed based on their inclusion of the three perspectives as well as the ease of adaptation to the Ugandan context.

Table 8 Comparison of selected games

Games	application areas	goals	The initialisation of the game	number and type of players	user interface	performance feedback	game portability
Power	Power	To learn about the roles of cooperatives in the energy system. Get insights into how the energy system works. To understand the interests of other stakeholders in the energy system.	Game instructions available	No: 7 local authority local energy cooperative 2 power companies grid operator housing corporation installer	Board Game	Detailed debriefing at the end of the game	Board game. Available for self-print
Nexus Game!	Food-water-energy nexus. Trans-boundary resource management	Food-water-energy nexus. Trans-boundary resource management	Requires a trained moderator	No: 8-24 For two countries: prime minister, water minister, energy minister, and agricultural minister.	Board Game	Detailed debriefing at the end of the game 1-2 hours	Board game. Paid and ordered based on requirements
The Energy Transition Game	Energy Transition	To foster a deeper understanding of the economic, social, and environmental factors that influence the energy transition and to facilitate discussions and collaboration among stakeholders.	Requires a trained moderator	No: 12-36 players energy producers, technology startups, energy providers, ministry of energy, consumers, environmental NGOs etc.	Board Game	Detailed debriefing at the end of the game 1-2 hours	Board game. Paid and ordered based on requirements
The World's Future	Various aspects of global sustainable development/ 17 sustainable development goals, e.g. health, energy, food, etc.	To understand the interconnectedness of social, economic, technological, natural resource management and environmental systems on an international/global scale	Requires a trained moderator	No: 9-36 people Type: Policymakers	Board Game & Online	Detailed debriefing at the end of the game 1-2 hours	Board game. Paid and ordered based on requirements

Combining the information from the table above and looking at whether the games contain the variables listed in Table 7, we come up with the comparison below;

1. All four games are role-playing board games with rules to represent the dynamics of the games (user interface and type of simulation). Role-playing assists in demonstrating the socio-technical and political perspectives as different roles compete to realise their particular goals or interests within the games. Only the Power game and the Energy Transition Game include the final energy consumers as part of their role-play, and only the Power game has an exact role for Energy Cooperatives.
2. All four games are scenario-based and include navigation through specific policies to reach specified goals. Playing out scenarios allows different factors affecting energy demand, growth or decline to be discovered. However, the extent to which this can be explored may be affected by how many other elements the games aim to explore. The Nexus Game and World's Future include a number of other aspects, e.g., Food, Water, Health, etc., whereas this may be good in further illustrating the complexities faced by governments on a national level the provision to focus on lower levels and study in detail, specific dynamics may be less apparent.
3. Additionally, two games are location-specific, i.e., the Power game based in the Netherlands and the Nexus game designed for the SADC region. This means that the technological elements within the game are already predetermined, making it more complex to adapt to the game. However, this does not invalidate the usefulness of the games, which could still work to simulate negotiation processes and highlight the difficulties of achieving optimal solutions in complex systems.

From the above comparison, Nexus Game and the World's Future Game are eliminated based on their large scope compared to the intended study. The Energy Transition Game and Power Game are both about the energy transition. However, they can still be used for this research because they both include the creation of an energy portfolio based on different technology alternatives, which is a pivotal variable. The edge the Power Game has over the Energy Transition Game is the embedded electric cooperative role. Although the Energy Transition Game has the option for modification (which possibly includes the addition of the role), at the time of this research, the game developers had limited availability to moderate the game.

Hence, this research has selected the Power game for ongoing utilisation. Subsequent sections will delve into the modifications implemented in the game, followed by insights gained from game testing, all leading up to the final gameplay experience.

4.3 Modification of the Power Game

4.3.1 Original Game Description

The initial aim of the game was for the players of a fictional municipality named Voordendam to make their municipality the most sustainable in the Netherlands. In order to achieve this goal, the municipality, in consultation with the business community and its residents, signed a Sustainable Energy Agreement for 16 years (4 rounds). The goal of the agreement is to generate or save eight units of renewable energy compared to the initial situation. This is done on two conditions: sufficient energy is supplied to meet the municipality's demand, and Voordendam remains an attractive place to live in. Initially, the municipality uses ten energy units supplied by nine coal-fired power plants and one wind farm. Sustainability is achieved by building wind and solar farms or by saving energy.

Payment for these sustainability options is made using money (called Daalders during the game) and hearts. Hearts represent support, so, for example, more hearts are needed to build a wind turbine, which the residents protest due to the effect on landscape aesthetics. Some of the players have the option to exchange hearts for Daalders as a way of marketing strategy or vice versa to acquire money for investment.

In addition to the common goal, each player has personal goals regarding sustainability, support, market share, security of supply and profit. The player who has achieved his or her personal goals at the end of the game is the winner, but only when the common goal is also met. Additionally, each round of the game consists of 5 phases:

Phase 1: Each round begins with a local news item that states what the players need to consider in the upcoming round. For the original game, four news items are presented for each round regarding protests against wind farms, the need for demand-side management to improve grid stability, increasing energy prices, and reduced costs of solar panels. There is also an interim news item about the institution of a tax for producers of grey energy. These news items not only provide the rules of the game but also reflect real-life complexities that actors in the Netherlands need to overcome, for example, the protests against wind farms [(Pascoe, 2022), Times (2021)], demand side management options being explored (Silicon Canals, 2023), and the soaring energy prices [(Carbonaro, 2022), (Times, 2022)].

Phase 2: In the second phase, the grid operator prepares the electricity grid for the arrival of renewable energy. First, he creates an inventory of what the other players would like to build in the round. Then, he/she builds the necessary grid connections or buffer capacity (batteries). Buffer capacity takes two forms: coal power plants or batteries.

Phase 3: In phase three, the players must negotiate whether to build new energy facilities, maintain existing ones or save energy. This includes agreeing about who pays for what.

Phase 4: In phase 4, everyone is paid out. Some roles are paid a fixed income and based on income from investments. Fines may also be handed out this round if any players neglect their duties. The first fines are handed to the energy suppliers if less than ten energy units are provided in the round. Then, to the grid operator, in case there is insufficient grid capacity for the new generation units or insufficient buffer capacity. The buffer capacity units must equal the number of solar and wind farms.

Phase 5: In the final phase, the group reflects on the news report from phase one. Depending on the results, some players may be rewarded or fined. The round is successful if the goal of the news report is achieved. Additionally, one of the players is asked to reflect on their goals each round. Phase 5 represents the progress monitoring phase of the game.

4.3.2 Adapting the game

Now that we have looked at the setup of the original game, we proceed to elaborate on the changes made to fit the game for use in this study. Some of the changes made have been highlighted in this report's previous chapters, including the electricity generation options and game roles to match the Ugandan context. The adaptation also included translating the original game from Dutch to English. Appendix A includes the translation and adaptations to the game manual, roles and rules.

4.3.2.1 Role Adaptations

The roles were adjusted based on the interactions initially set within the game and the roles of the different actors, as derived from the system analysis in Chapter 2. Below, we summarise the roles and their interactions before highlighting the changes made.

The interactions between the roles in the game.

The transactions between the players are based on their roles in the game. Appendix A contains the game rules, roles and manual from which these interactions are derived.

1. The renewable energy company, power company and Local energy cooperative are the electricity providers for the municipality. They must supply enough energy units each round to meet the energy demand.
2. The municipality, the local energy cooperative and the renewable energy company spearhead the sustainability goal. However, whereas the municipality and renewable energy company aim to achieve eight units of sustainable energy, the local energy cooperative has a personal goal of at least nine sustainable units by the end of the fourth round.
3. The grid operator and the municipality do not participate in commercial activities. The municipality can, however, give subsidies to the other players. The municipality is responsible for keeping the residents happy by ensuring their municipality is beautiful and keeping track of the events in the news report.
4. The renewable energy company and the power company are commercial entities. Therefore, they have the personal goal of having the largest market share.
5. The installer earns using the Energy Service Company (ESCo) model. An ESCo is a company that offers energy services, which may include implementing energy-efficiency projects (and also renewable energy projects) and, in many cases, on a turn-key basis (E3p, n.d.). The three main characteristics of an ESCO are: ESCOS guarantee energy savings and provision of the same level of energy service at a lower cost. The remuneration of ESCOS is directly tied to energy savings achieved. ESCOs can finance or assist in arranging financing for the operation of an energy system by providing a savings guarantee (E3p, n.d.).
6. The housing corporation owns resident properties within the municipality. Their goals are mainly toward sustainability, improving their image by making their homes more energy efficient and becoming co-shareholders in solar farms. The housing cooperation earns the least fixed income compared to the municipality and grid operator.

Interactions between the actors in Uganda's rural electrification system.

1. MEMD is the overall policy head of Uganda's Electricity Supply Industry to whom ERA and REA are answerable. Their mandate is establishing, promoting, and developing Energy and Mineral Resources for social and economic development.
2. ERA is the legal supervisor of Uganda's Electricity Supply Industry and is mandated to issue licences with the attendant License Terms and Conditions for Electricity Generation, Transmission, Distribution, Sale, Import, and Export of Electricity. ERA is also mandated to establish a Tariff structure and approve rates of charges.

3. REA is in charge of operationalising the rural electrification function, manages the rural electrification fund and provides subsidies to support rural electrification projects.
4. The generation segment consists of a combination of Government of Uganda (GOU)-owned power plants, Independent Power producers (IPPs), and Public-Private Partnerships (PPPs).
5. UETCL solely manages the high voltage transmission grid, directly executes Power Purchase Agreements with Independent Power Producers, and manages Power Plants' scheduling and actual dispatching.
6. Much like the generation segment, distribution has also been liberalised to include private companies, electric cooperatives, and GOU-owned Uganda Electricity Distribution Company Ltd (UEDCL).

Based on the above interactions, the roles were matched as closely as possible so that minimal change would be made to the interactions already in the game. As such, only the titles of two role titles were adjusted, i.e., the REA replaced the Municipality, and Residents replaced the Housing Corporation. All the other roles remained the same, and the Local Installer role, though more specific to Europe, was maintained to explore the possibility of its integration in Uganda.

Table 9 Game role adjustment

Dutch Version	**Translation by DeepL**	**Modification**	**Real-life Context**
Duurzaam Energiebedrijf	Sustainable Energy Company	Renewable Energy Company	The role represents IPPs in the Ugandan context dealing in renewable energy.
Energiebedrijf	Energy company	Power Company	The role represents IPPs in the Ugandan context dealing in non-renewable energy.
Netbeheerder	Grid operator	Grid Operator	The role represents more so the role of UEDCL compared to other private distribution concessionaires.
Lokale energiecoöperatie	Local energy cooperative	Local Energy Cooperative	The role represents the local energy cooperatives in the Ugandan context, however, in the

Dutch Version	Translation by DeepL	Modification	Real-life Context
			game, there is a separate role to handle distribution compared to the real-world scenario.
Gemeente	Municipality	Rural Electrification Agency	The role represents the now Rural Electrification Department.
Lokale installateur	Local installer	Local Installer	As explained in the introduction text.
Woningbouwcorporatie	Housing corporation	Residents	This role was adjusted to the residents of the territory due to the variance in housing arrangements between Uganda and the Netherlands.

4.3.2.2 Energy technology adaptations

The original game considered three main electricity generation sources as commonly used in the Netherlands i.e., Coal power plants, wind turbines and solar farms. For this research, the plan was to replace the three power sources within the game with the top three sources derived in Chapter two i.e.,:

1. **Solar PV mini-grids (at mini- and micro-scale)**
2. **Small-hydro mini-grids**
3. **Grid-extension**
4. Hybrid Diesel Generator mini-grids
5. Biomass

However, as seen from the discussion on the phases in the game above, the need for buffer capacity is a big component of the game's mechanics, something that is not necessary with the use of small hydro-farms or grid extension. Therefore in order to avoid an imbalance to the mechanics of the game, we opted for only solar energy, but at two scales, mini- and micro scale.

The mini-scale solar farms replaced the wind farms in the game, as seen in Figures 12 and 13 below. It costs more to construct than the micro-scale solar, which were maintained as solar farms already in the game. Additionally, as the Power! Game is an energy transition game, more focus was then placed on the change from one form of energy i.e., diesel generators, commonly used for rural electrification replaced the coal powerplants that are not present in Uganda.

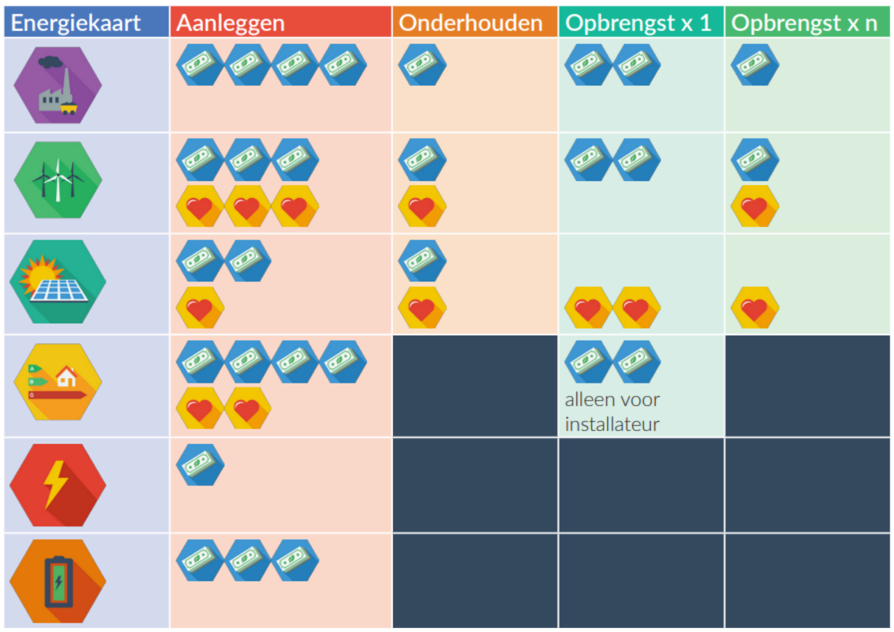


Figure 12 Original payment schedule and energy card map

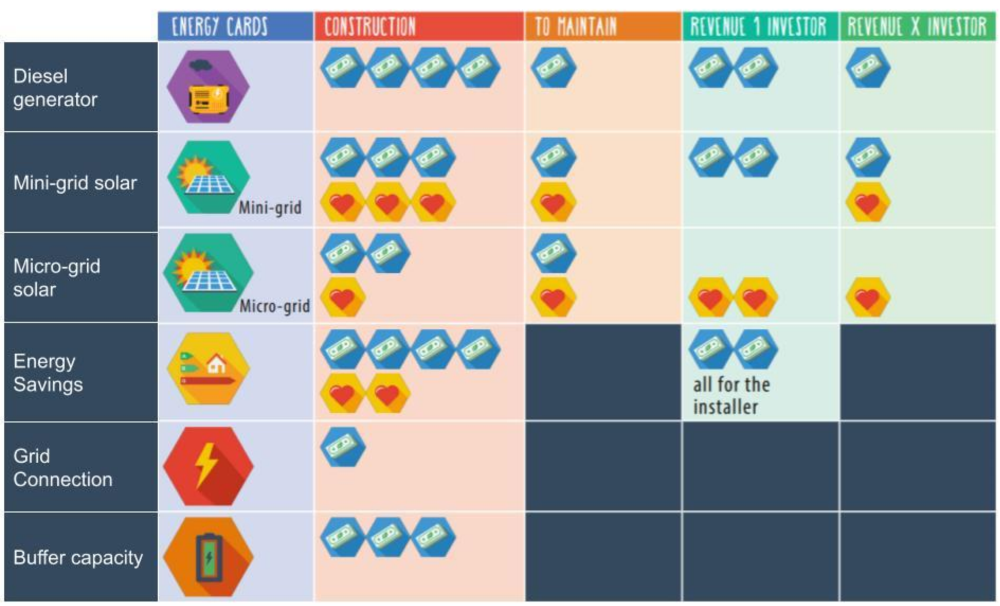


Figure 13 Adjusted energy card maps

Game Tests

Tests of the game were conducted to verify the mechanics of the game, and the decisions described above were based on the results of these game tests. In total, three tests of the game were conducted before the final game with the electricity sector stakeholders. Two sessions were held within the university (TU Delft) and one in Uganda.

Before the above final changes were made, the first game test included changes to some of the mechanics of the game in order to fit more closely to the Ugandan context. These adjustments included:

i. Combining the role of the grid operator with that of REA to match the role of REA whereby REA does the initial installation of the distribution network following the advice of the local cooperative.
ii. To create a differentiation between mini-grid and micro-grid solar, the first iteration was made so that one mini-grid could take up two spaces on the board instead of one.
iii. To create the semblance of increasing energy supply, instead of nine diesel plants owned by the power company in the beginning situation of the game, the game was made to start with only three diesel generators and one mini-grid solar. The task then was to increase the power supply by adding at least two new energy units each round.

It was quickly realised, however, that combining the roles made it difficult for a single player to perform their role well enough, and distortions to the 'back-calculated' mechanics of the game quickly threw it off balance, making it hard for any of the players to achieve their goals. Therefore, the game reverted to its initial dynamics.

The third and final game test in Uganda was particularly informative on the engagement and learning benefits of serious games. Despite having limited knowledge of the electricity sector system, the players were able to relate to the news items highlighted within the game and quickly picked up enthusiasm for the roles played. In the final game, one of the participants even asked for a "fifth round". Many of the insights shared by the non-experts were comparable with points made in the literature. For example, the participant playing the power company noted the need for a clear roadmap to plan for investments. The 'residents' player was able to express the constraint in investment in solar owing to limited resources and the relief in collaborating and co-investing with other players like the energy cooperative. Most players expressed the need for collaboration between actors in achieving the overall goal and the appreciation of how individual interests can hamper the realisation of common goals.

4.4 Final Game

To recap, the main objective for using a serious game in this research was to explore the potential application of serious games as tools for coordination, learning, and promoting behavioural change within Uganda's energy sector for more sustainable energy development. To achieve this, eight stakeholders comprising employees from MEMD and private entities working in electricity efficiency, generation, distribution, and social engagement participated in the interviews, questionnaires and the final game, providing the information for this research.

Additionally, an assessment of the learning outcomes of the game was done at the end with the participants, which included a questionnaire about the participants' prior gaming experience and the possible usability of the game in their work. Appendix B 2 shows the list of questions answered by the participants.

At the start of the game, the participants were allowed to select any available roles. However, it was found that the roles they selected were similar to their actual work or with whom they had close dialogue. The game ran for approximately three hours; notably, the learning curve was much faster than the game tests.

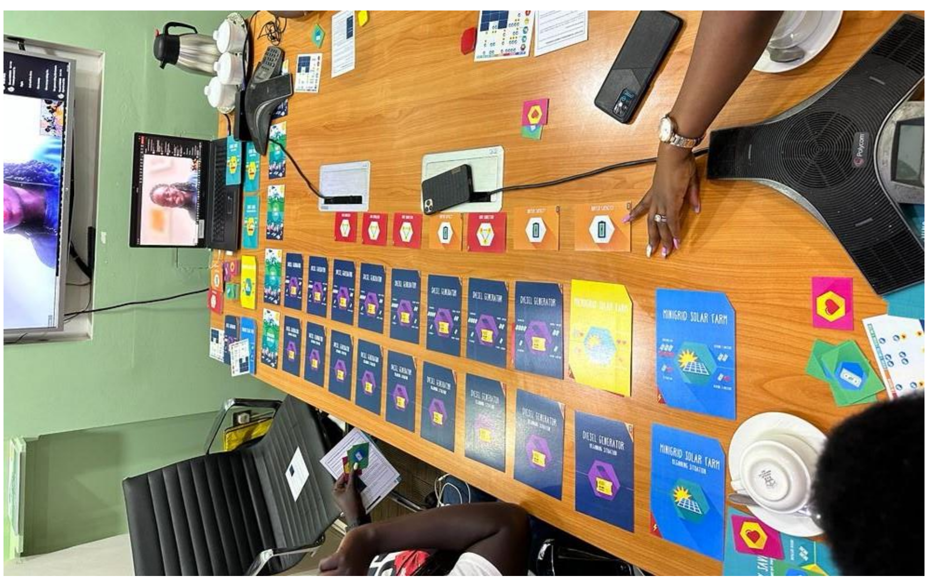


Figure 14 The beginning situation and first round of the game

The game's set-up was such that players lay down the energy cards each round to form a map that facilitates comparing investment decisions and policy impacts each round. In terms of the gaming activity, the group setting was successful in encouraging active participation.

Figure 15 Final game map at the end of round four

Figure 15 above shows the final energy mix at the end of the four rounds of the game. A key for the different energy cards is shown in Appendix A1.

The game's general results show that until round three, diesel generators continued to dominate the energy mix. More deliberate effort towards the transition came after the policy on Polluter tax was introduced. After that, there was a much heavier investment in micro-grid solar and energy savings.

From the beginning, the mini-grid was maintained, but only until round three. At the beginning of the game, the cooperative and the renewable energy company co-owned the mini-grid, and the cooperative had an interim objective to co-invest in two new solar farms by the end of round two. Interestingly, in the last two sessions of the game, the participants playing the cooperative failed at this objective. The challenge both participants cited was that the ‘hearts’ or support were insufficient to contribute solely to the higher-cost investments. Instead, these players lobbied for collaborations with the other players to invest in micro-solar powerplants and energy savings. The local installer performed very well in both games, winning during the game test and coming in second in the final game. The players appreciated the perceived benefits of energy savings, which sparked a more detailed discussion in the next chapter. The renewable energy company emerged as the victor in the game, and the player accredited the enthusiasm towards renewable energy for their success.

5 Discussion

5.1 On the results of the game

After the game was played, players participated in a round-table discussion on their roles and game strategies, as well as their interactions with the other roles in the game. The insights discussed below resulted from the discussion. Participants were asked questions about their roles in the game, their game strategy, insights gained from playing it, and the possible use of games in the Ugandan context.

For the Power game, the main goal is to assess the roles of cooperatives in the energy system. Regarding this objective, the participants who played the cooperative mainly contributed to the energy profile development in the form of hearts/ support. However, during the gameplay, it was clear that hearts (support) were insufficient for the cooperatives to actively participate in energy investments, as was seen in their inability to achieve their interim objective. With this, the participants in the game gathered that the strength of the cooperative model lay in facilitating and promoting demand-side management initiatives like the promotion of energy efficiency, conservation and other electrification projects due to their proximity to the communities, as a way to support private sector partners and government efforts.

In the real-life context, the cooperative primary operations are in the distribution of electricity to designated territories, and the stakeholders shared some contradictory views regarding the subsidisation of cooperative efforts. Whereas some saw the need for subsidisation of electricity prices to facilitate the adoption of electricity by the poorer populations, opposing stakeholders, especially in the generation sector, pointed out the impracticability as there are still expenses to be met for safe power generation. However, previous government efforts to subsidise electricity have also failed to meet the expected electricity need in the country, elucidating the possible need to change the avenues and approaches for subsidisation (Fashina et al., 2018). The World Bank 2015 report on the evaluation of concessionaries even suggested that the concession of the monopoly distribution company (UMEME) could have had a path for the leading distribution utility to electrify regions outside its service area eventually rather than introduce less financially capable service providers. Because of this gap in the institutional capacity of cooperatives, the GoU could consider scaling down their roles to focus more on promoting electrification with room to grow into investment.

The power company in the last two game sessions placed in the middle when it came to achieving its goals, which included maintaining market share despite starting with the highest income and having access to loans from the game's bank. Here, two important points come up. In the final game, the participant who played the role based their strategy on what happens in the real-life context, i.e., distributed generation is the majority of the time also handled by the concessionary distribution company. Therefore, in their gameplay, the participant focused on supporting investment in the grid, which a different role, the grid operator, should have handled. This reflects an anomaly in the game choice that did not accurately portray the situation on ground.

Second is the issue of the sudden loss of investment for the power company when, in the game, players had to switch from diesel generators to sustainable energy. This affected the power company's income in the game. In the real-life context, the investments of Independent Power Producers (both fossil and renewable energy) are cushioned by subsidies and payment by UETCL for the entire capacity of the power plants. This results in 'Deemed Energy', unused electricity due to the stark difference between the electricity produced and used. The disparity is caused by the issues previously mentioned, i.e., low demand and poor distribution and transmission infrastructure, resulting in futile expenditures of the country's budget and high tariff costs for the consumers [(Kazibwe, 2023) (Nakaweesi, 2022)]. The alternative brought up and also previously mentioned in Chapter Two is the integration of hybrid systems as a transitional alternative for fossil IPPs. Also, GoU should consider focusing energy development on fortifying the distribution grid rather than continuing generation infrastructure development (Musisi & Owiny, 2022).

Other interesting insights from the game were the persistence of diesel generators up until the third round, despite the emphasis on sustainability in the game's goals, and even shared by the very same participants during the survey part of the research. During the game, the existing availability and lower maintenance price instead of new investment in renewable options caused players to opt for diesel generators. It was not until the legislation on polluting energy tax was enforced and the significant reduction in micro-grids that players opted for the change.

Another alternative that was explored during the game to meet energy demand was the use of energy savings. The new Energy Policy 2023 focuses on adopting several energy-efficient measures, including increased communication, creating standards for energy efficiency, and promoting initiatives. In the game, the local installer is an actor based on the EU's Energy Service Company Model and was very successful in mobilising the adoption of energy savings among the institutions that owned property in the game. The same market or model could also be adopted in the Ugandan context to promote investment in energy efficiency. However, such an initiative would succeed with solid policy enforcement, especially regarding energy performance standards.

Overall, the gaming session was helpful as a learning tool for all participants. The insights shared above indicate the usefulness of gaming in opening the door for discussion among the stakeholders despite the diversity of their work fields.

5.2 On the possible adoption of serious games in Uganda's energy sector

The participants were also asked questions regarding their previous use of serious games and perceived usefulness in their work in the Ugandan energy sector. None of the participants had previous interactions with serious games; however, all agreed that using games could help facilitate collaboration between the various sections within the energy department. Similar successful inter-organisational meetings and collaborations have been had, for example, the Energy Tables in the Netherlands involving both public and private parties regarding the energy transition (Ebskamp & Kalshoven, 2016). Figure 16 below shows the departments and agencies within the energy and minerals sector that must coordinate efforts to meet the country's overall energy goals. Each agency drafts its strategies based on the overarching policies for fulfilling its duties. However, often, there is an overlap and confusion over responsibilities. The participants in the game acknowledged the potential of using games similar to the one played to develop cohesive strategies across departments.

The discussion also included potential barriers towards the implementation of the serious games. For starters, the lack of prior knowledge among the participants could indicate the inadequate knowledge of serious games and their perceived benefits, which could hamper support to use the tools. This inadequacy also feeds into a lack of technical and financial capacity to develop the games in-house to suit more specified needs better. The enthusiasm over the use of games could also be due to the relatively young age of the participants (below 40 years). One of the respondents shared that the old-school leadership within the public sector may be more hesitant to accept what could be seen as conceptual and idealistic practices towards the sector's development. They proposed that a good starting point for using games would be within more flexible private energy companies.

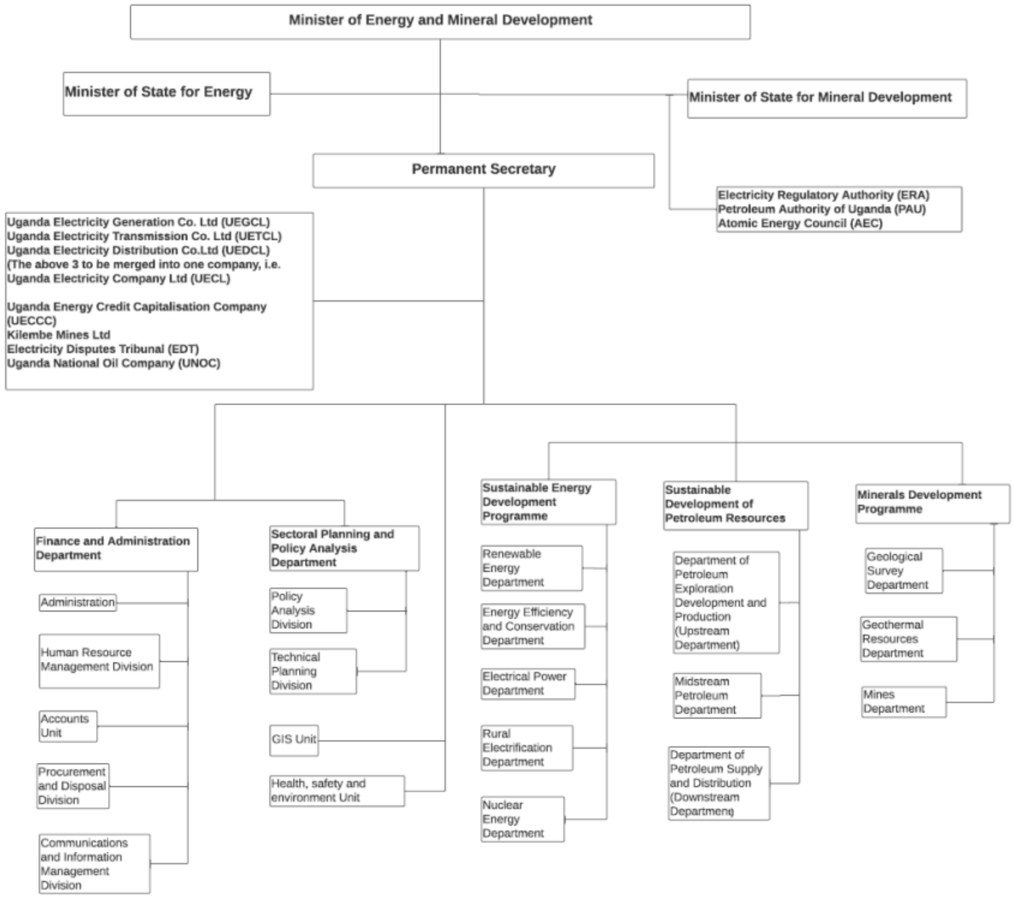


Figure 16: Structure of Departments and Agencies within the Energy and Mineral Sector (MEMD, 2023)

6 Conclusion

This research aimed to determine plausible pathways for the realisation of the development of rural electrification in Uganda using a serious game and considering the three perspectives prescribed by Cherp et al. As described in the introduction chapter, the actualisation of this goal depends on several often competing criteria and diverse actor interests. Therefore, to come up with the best-selected solutions to the complex problem, the main research question was broken down into four sub-questions loosely based on the steps required for a multi-criteria decision analysis. These included 1) Problem Structuring, 2) Determining the requirements, 3) Establishing Goals, 4) Identifying Alternatives, 5) Defining criteria, 6) Selecting a decision-making tool, 7) Evaluating alternatives against criteria, and finally 8) Validating solutions against the problem statement. In the conclusion chapter, we review each sub-question, the research method used to answer it and present a summary of the findings, culminating in answering the main research question. The main research methods used were literature reviews, surveys, questionnaires and a pre-existing serious game.

1. **What alternatives are available for electricity generation based on the requirements and goals of Uganda's energy policies?**

This question aimed to identify the best electricity generation alternatives for rural electrification in Uganda to be used within the game. From a literature review, we found that several policies cover plans to exploit the country's energy resources, including the overarching policies that cover a number of resources and technologies like the Energy Policy (2023 and 2002), the Renewable Energy Policy, In addition, strategies like the Rural Electrification Strategy and Plan (RESP II) mention more specific generation technologies to be considered, particularly for rural electrification. From these policies and strategies, the list of generation resources and technologies was derived, which included large-hydro and mini-hydro (run-of-the-river dams), oil (thermal power plants), nuclear (nuclear powerplants), solar (Photo-voltaic systems), biomass (CHP plants), geothermal (Geothermal power station) and peat (peat-fired powerplants).

The above list was further evaluated based on criteria derived from both policy and literature. The main criteria derived included **sustainability, maturity of technology, reduction of prices, political support and social acceptance**.

Stakeholders comprising employees from public and private energy entities were asked to rank these criteria and generation alternatives in order of importance and feasibility for use in rural electrification, respectively. Sustainability, technology maturity, and reduction in energy prices emerged as the top considerations for analysing energy resources and technologies for rural electrification in Uganda. Respondents also highlighted the importance of political support and social acceptance, recognising their interdependence and impact on the successful implementation of energy projects. Other resource-specific attributes, such as location specificity and modularity, were also considered for the evaluation. The ranking of generation alternatives included large-scale electricity sources like hydro and solar, placing highest. However, their suitability for rural electrification depends on the grid's densification. This was followed closely by solar mini-grids (and micro-grids) and, thirdly, mini-hydro.

These criteria encompass the interplay between the perspectives, especially the techno-economic and socio-technological perspectives. Techno-economic considerations underscore the maturity and sustainability of energy technologies, influencing their feasibility, expected outputs, and cost-effectiveness. Pursuing sustainable energy sources aligns with socio-technical dimensions, wherein societal values, environmental impacts, and public engagement influence the adoption and acceptance of energy projects. This socio-technical landscape intertwines with political dynamics, as policy frameworks and institutional support drive energy governance, shape market competition, and influence the prioritisation of specific technologies. The final list of the electricity generation alternatives to be considered included Solar PV mini-grids (at mini- and micro-scale), Small-hydro mini-grids, Grid-extension, Hybrid Diesel Generator mini-grids and Biomass.

From the above findings, we can conclude that the country's strategy aims to balance promoting renewable energy sources, enhancing energy efficiency, ensuring affordability, and gaining political and social support for energy projects to ensure sustainable energy development. The extent to which this is achievable was determined through the serious game covered in the proceeding sub-questions.

2. **Who are the critical actors and stakeholders within the realm of rural electrification in Uganda?**

The primary function of this sub-question was to determine the stakeholders within the rural electrification sector, i.e., those who make the decisions and those who are affected by or are interest groups for the decisions made. The identified actors informed the roles played during the game. The stakeholders were identified through an energy sector analysis from the energy policy documents and cited scientific literature in Chapter Two.

The analysis yielded a complex web of actors and entities, encompassing governmental bodies, regulatory institutions, private sector entities, and community-based cooperatives. Central to this endeavour is the Ministry of Energy and Mineral Development (MEMD), which spearheads the nation's electricity supply policy, setting overarching goals and guiding energy development strategies. Aligned with MEMD's efforts, the Electricity Regulation Authority (ERA) is the regulatory force overseeing all electricity operators. Formerly the Rural Electrification Agency (REA), this entity undertakes the operationalisation of rural electrification targets as a department under MEMD, fostering electricity access in underserved communities by collaborating with various stakeholders, including those within the Sustainable Energy Development Program of the MEMD.

Uganda's private sector also occupies a significant role in rural electrification. Electricity sector privatisation has encouraged Independent Power Producers (IPPs) and private distribution firms to engage in generation, distribution, and services, infusing competition and innovation. Electric cooperatives, championed by RESP II, similarly aim to expand access and mitigate business risks in rural regions, yet challenges like vandalism and economic constraints have surfaced.

The multifaceted dynamics of Uganda's electrification stakeholders are intertwined and diverse, each contributing distinct perspectives and strategies towards universal electricity access. Challenges like high costs, low demand, and the need for sustainable inclusivity persist. Overcoming these hurdles necessitates collaborative efforts among these crucial players, which the research aims to achieve through utilising the game.

3. **What is the required structure of the selected pre-existing game?**

The game was the primary tool of analysis for the research. The choice of the game was made based mainly on its ability to accommodate the analysis of the techno-economic, socio-technical and political perspectives based on the variables from Cherp et al. The techno-economic aspect was encompassed by evaluating available energy resources, distribution systems, and cost implications. Socio-technical perspectives involved examining the transition from traditional to sustainable energy sources and the complex interplay of various stakeholders. Furthermore, the political viewpoint was encompassed by reflecting on the country's energy policies and recent developments.

Other considerations included the game's availability, customizability, and potential for fostering collaboration. Preference was given to board games to encourage face-to-face engagement among participants, which encouraged the productive discussions highlighted in the Discussion chapter.

The games were sourced from the online platforms Science Direct, Google, and game database websites Games4sustainability.org and Gamesforchange.org. Out of four pre-selected games, the Power! Game by TNO emerged as the optimal choice.

4. **How do stakeholder decisions affect Uganda's energy mix, and can serious games enhance their decision-making?**

The results of this sub-question were derived from playing the final adapted game. The Power! Game selected previously was adjusted to include mini-grid and micro-grid solar from the generation alternatives derived from sub-question one, and the roles were based on the critical actors from sub-question two. The game was played by employees from public and private entities within Uganda's energy sector to simulate real-world scenarios and dynamics. The changes leading up to the game's final energy mix were visualised after four rounds and reflected the players' interplay of strategies and objectives based on their game roles and real-life work roles.

At the game's outset, diesel generators dominated the energy mix, reflecting the prevailing reliance on conventional sources. However, a shift towards more sustainable options became evident as the game progressed. This shift was notably triggered by the introduction the Polluter tax policy, which incentivised players to reevaluate their choices in light of environmental implications and economic incentives. Players representing the renewable energy company and the local installer performed well, attributing their success to enthusiasm built in the game around renewables and energy savings, which could be said to be indicative of the role of campaigns and consumer sensitisation. Other players, like the power company and the cooperative, struggled in their gameplay due to choices made with game strategy and the challenges of higher-cost investments. The only way for the cooperative was through collaboration with other parties to make impactful change.

Overall, the serious game offered, to an extent, a representation of how stakeholders navigate the complex landscape of the energy system. The energy mix's evolution throughout the game showcased the interdependence of diverse strategies, the significance of collaboration, and the role of policies in shaping the energy sector's trajectory towards sustainability.

The main research question

The main research question for this research was: **What are the plausible pathways for rural electrification development in Uganda, considering the techno-economic, socio-technical, and political perspectives, using a serious game?** By playing the game, we were able to devise the pathways below. These steps provide a framework for the GoU through the designated Ministry and associated stakeholders to enhance their efforts towards sustainable energy development in rural Uganda.

Adjusting Cooperative Roles: The current roles for cooperatives as distribution concessionaires have proven to be burdensome (as seen in the literature cited), with the closing of nearly all previously developed entities and their operations being taken over by UEDCL. The same was observed during the game, as the local energy cooperative struggled to reach its investment goals. However, the game also highlighted that cooperatives could continue to play a pivotal role in promoting demand-side management initiatives, such as promoting the growth of electricity use, energy efficiency and conservation. Their proximity to communities positions them to support private sector partners and government efforts in these areas.

Solar Technologies Focus: Solar micro-grids emerged as the dominant energy option at the end of the game, thus backing the strategy for using micro-scale solar in promoting faster electricity access to remote, sparsely populated and nucleated rural societies. However, less mentioned in policy are plans for incorporating distribution infrastructure for interconnecting distributed grids to eventually benefit from the cost and reliability benefits of a wider connected grid. Incorporating the infrastructure and continued support for small-scale solar grids aligns with sustainability objectives and capitalises on Uganda's solar potential.

Inclusion of private-sector actors in Energy-Saving and Efficiency: Exploring energy-saving and efficiency options offers a viable pathway to improve electricity availability. The game showed that energy savings initiatives can be successfully promoted, primarily when facilitated by actors with expertise, such as local installers, instead of spearheaded by the public entities to reap the benefits of market institutions as with the unbundling of the rest of the sector. Integrating energy-efficient measures can contribute to a more sustainable energy mix.

Creative Subsidies: The proceeding debate from the game brought up conflicting views on cooperative and consumer subsidies. The research highlighted the need for a refined approach to subsidies that addresses social integration and financial feasibility in a way that does not create unsustainable subsidy dependency. In the game, however, it was observed that implementing creative subsidies to support stakeholders like residents and cooperatives could stimulate rural electrification.

Enhanced Collaboration and using Predictive tools for policy: Improving collaboration among stakeholders is crucial for attaining the set energy strategies and objectives. More explicit roles and coordinated strategies across departments and agencies within the energy sector can lead to more effective efforts and resource allocation.

Perhaps the most vital recommendation from this research is thus the use of scenario-building and simulation tools such as serious games to foster comprehensive discussion between both private and public entities in the energy sector. The usefulness of serious gaming has been demonstrated through this research, by providing insights into various scenarios and potential outcomes for rural electrification. These outcomes and tools not only facilitate decision-making, but can also be used for policy development, and learning and sensitization by a spectrum of stakeholders.

Finally, derived from a multi-dimensional analysis, the identified pathways offer valuable insights for guiding rural electrification development in Uganda. By adopting the above recommendations, Uganda can navigate a sustainable and inclusive path towards rural electrification. These pathways address the technological, economic, socio-technical and political aspects crucial for successful implementation.

7 Final Reflection

While the study provides valuable insights into the pathways for rural electrification development in Uganda, it is important to acknowledge the potential limitations to inform end-users, like researchers and decision-makers, of the possible constraints and considerations when implementing the study findings.

7.1 On the adopted methodology

The research process primarily relies on qualitative data obtained from literature reviews, game sessions and discussions, and to a much lesser extent, quantitative approaches such as surveys. While qualitative data provide valuable insights, they might not provide a complete quantitative understanding of the impact and feasibility of the proposed pathways. The first recommendation for future research would be to use fully the MCDA process and quantitative methodology, using this report as a benchmark for comparison of the findings.

A second constraint and consequent recommendation was the shortage of time to design a more specified game that would include more context-specific analyses, especially on the economic perspective relating more towards energy purchasing. Therefore, as a recommendation, decision-makers could benefit more from a closer adaptation of a serious game to accommodate even more context-specific dynamics. Lastly, it is important to consider the assumptions and simplifications made in designing serious games and interpreting results.

Additionally, concerning the execution of the study, conducting the interviews and game sessions remotely was a challenge. Direct requests for interviews with associated parties proved futile, and it was only through personable requests for connections to some stakeholders that I was able to yield positive results. Very close follow-up was required in order to receive the feedback owing to the time differences and diverse work schedules to be considered. The difficulty in getting participants affected the sample size and composition; only eight energy sector participants assisted in this research. While valuable, the participants' perspective might not encompass the entire spectrum of stakeholders involved in rural electrification. Nonetheless, to verify their inputs, most of the information shared was backed by evidence from literature and news reports.

7.2 On the chosen scope of the research

The study focuses on the context of Uganda, which is a single case study. While informative, the findings may not fully capture the nuances and complexities of rural electrification in other countries. Also, including the limitations of institutional transplantation explained within the report, special considerations must be taken in applying the final pathways to other contexts.

Finally, it is important to note that socio-technical systems, such as rural electrification, are dynamic and influenced by changes over time, such as technological advancements, policy shifts, and economic fluctuations. These translate to continued adaptations of the suggested pathways from this study. However, predictive tools such as serious gaming make these easier to adapt.

8 References

Apfel, D. (2022). Renewable energy transition in Senegal? Exploring the dynamics of emerging paths to a sustainable energy system. *Energy Research and Social Science*, *92*, 102771. https://doi.org/10.1016/j.erss.2022.102771

Arvidson, A. & Woodsworth, G.. (2006). A regional energy scale-up initiative in East Africa. 19. 1-3.

Athumani, H. (2023, February 28). Uganda set to begin oil drilling despite environmental concerns [Video]. VOA. https://www.voanews.com/a/uganda-set-to-begin-oil-drilling-despite-environmental-concerns-/6983075.html

Atomic Energy Act (2008) (No. 24 of 2008). (n.d.). Ecolex. https://www.ecolex.org/details/legislation/atomic-energy-act-2008-no-24-of-2008-lex-faoc138017/

Aubert, A. H., Bauer, R., & Lienert, J. (2018). A review of water-related serious games to specify use in environmental Multi-Criteria Decision Analysis. Environmental Modelling and Software, 105, 64–78. https://doi.org/10.1016/j.envsoft.2018.03.023

Barnes, D. F. (2011). Effective solutions for rural electrification in developing countries: Lessons from successful programs. Current Opinion in Environmental Sustainability, 3(4), 260–264. https://doi.org/10.1016/j.cosust.2011.06.001

Belton, V., & Stewart, T. (2012). Multiple Criteria Decision Analysis: An Integrated Approach. Springer Science & Business Media.

Bhagavathy, S. M., & Pillai, G. N. (2018). PV Microgrid design for rural electrification. Designs, 2(3), 33. https://doi.org/10.3390/designs2030033

Bhandari, R., Arce, B. E., Sessa, V., & Adamou, R. (2021). Sustainability Assessment of Electricity Generation in Niger Using a Weighted Multi-Criteria Decision Approach. Sustainability, 13(1), 385. https://doi.org/10.3390/su13010385

Bonamini, G., Colombo, E., Llorca, N., & Sánchez-Soriano, J. (2019). Cost allocation for rural electrification using game theory: A case of distributed generation in rural India. Energy for Sustainable Development, 50, 139–152. https://doi.org/10.1016/j.esd.2019.01.007

Buchholz, T. A., & Volk, T. A. (2012). Considerations of Project Scale and Sustainability of Modern Bioenergy Systems in Uganda. Journal of Sustainable Forestry. https://doi.org/10.1080/10549811.2011.566540

Bungane, B. (2021, February 16). Solar minigrids coming to 49 villages in Uganda and Sierra Leone. ESI-Africa.com. https://www.esi-africa.com/renewable-energy/solar-minigrids-coming-to-49-villages-in-uganda-and-sierra-leone/

Burke, M., & Stephens, J. C. (2018). Political power and renewable energy futures: A critical review. Energy Research & Social Science, 35, 78–93. https://doi.org/10.1016/j.erss.2017.10.018

Buskirk, V., & Robert, D. (2006). Analysis of long-range clean energy investment scenarios for Eritrea, East Africa. Energy Policy, 34(14), 1807–1817. https://doi.org/10.1016/j.enpol.2004.12.023

Carbonaro, G. (2022, October 26). Energy bills are soaring in Europe. This is what countries are doing to help you pay them. Euronews. https://www.euronews.com/next/2022/10/26/energy-bills-are-soaring-in-europe-what-are-countries-doing-to-help-you-pay-them

Cartland, R., Sendegeya, A., & De Dieu, H. K. J. (2023). Performance analysis of a hybrid of solar photovoltaic, genset, and hydro of a Rural-Based Power Mini-Grid: Case Study of Kisiizi Hydro Power Mini-Grid, Uganda. Processes, 11(1), 175. https://doi.org/10.3390/pr11010175

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. K. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. Energy Research and Social Science, 37, 175–190. https://doi.org/10.1016/j.erss.2017.09.015

Choti, J., & Xydis, G. (2022). Harnessing offshore wind energy in east Africa: the next big move to lighting up the continent. Proceedings of the Institution of Civil Engineers, 175(6), 31–38. https://doi.org/10.1680/jcien.21.00253

Coenen, L., & Lopez, F. D. (2010). Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities. Journal of Cleaner Production, 18(12), 1149–1160. https://doi.org/10.1016/j.jclepro.2010.04.003

Creswell, J. W. (2008). Research design: Qualitative, Quantitative, and Mixed Methods Approaches. SAGE Publications, Incorporated.

Creswell, J. W., & Clark, V. L. P. (2017). Designing and conducting mixed methods research. SAGE Publications, Incorporated.

De Freitas, S., & Ketelhut, D. J. (2014). Introduction for the Journal of Information Sciences special issue on serious games. Information Sciences, 264, 1–3. https://doi.org/10.1016/j.ins.2014.01.036

E3p, T. (n.d.). Energy Service Companies (ESCOs). E3P. https://e3p.jrc.ec.europa.eu/node/190

E3p, T. (n.d.). Energy Service Companies (ESCOs). E3P. https://e3p.jrc.ec.europa.eu/node/190

Ebskamp, B., & Kalshoven, F. (2016). Visie op versnelling van de energietransitie: De Energietafel. In *www.argumentenfabriek.nl*. SSP & Cliteur.
Energy Profile: Uganda. (2022, August 24). IRENA. https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Uganda_Africa_RE_SP.pdf

Energy.nl. (2023, June 20). Serious game energietransitie: POWER! - Energy.nl. https://energy.nl/tools/serious-game-energietransitie/

Energypedia.(n.d.0https://energypedia.info/wiki/Impacts_of_Rural_Electrification_in_Uganda_2011-2019

ERA. (2018, February 27). Global Energy Transfer Feed in Tariff (GETFiT) Programme. https://www.era.go.ug/index.php/sector-overview/programmes/getfit

ERA. (2020, November 11). Uganda’s Electricity Sector Overview. https://www.era.go.ug/index.php/sector-overview/uganda-electricity-sector

ERA. (n.d.). Tariff schedules - ERA - Electricity Regulatory Authority. Retrieved August 23, 2023, from https://www.era.go.ug/index.php/tariffs/tariff-schedules

Fashina, A. A., Mundu, M. M., Akiyode, O. O., Abdullah, L., Sanni, D. M., & Ounyesiga, L. (2018). The Drivers and Barriers of Renewable Energy Applications and Development in Uganda: A Review. Clean Technologies, 1(1), 9–39. https://doi.org/10.3390/cleantechnol1010003

Filho, F. F., Santiago, Y. C., Lora, E. E. S., Palacio, J. C. E., & Del Olmo, O. A. (2021). Evaluation of the maturity level of biomass electricity generation technologies using the technology readiness level criteria. Journal of Cleaner Production, 295, 126426. https://doi.org/10.1016/j.jclepro.2021.126426

Galuszka, J., Martin, E., Nkurunziza, A., Oginga, J., Senyagwa, J., Teko, E., & Lah, O. (2021). East Africa’s Policy and Stakeholder Integration of Informal Operators in Electric

Mobility Transitions—Kigali, Nairobi, Kisumu and Dar es Salaam. Sustainability, 13(4), 1703. https://doi.org/10.3390/su13041703

Gaul, M., Schröder, M., Berg, C., Schmidt Matthias, Alff, U., Luh, V., & KfW Development Bank. (2019). The Impact of Rural Electrification: Results of the 2013 - 2019 Impact Monitoring of the Investments in Rural Electrification in West Nile Sub-Region, Uganda.

GIZ. (2022). SECTOR BRIEF UGANDA: Renewable Energy. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.giz.de/en/downloads/giz2022-en-sectorbrief-uganda-renewable-energy.pdf

Gunnarsdottir, I., Davidsdottir, B., Worrell, E., & Sigurgeirsdóttir, S. (2021). Sustainable energy development: History of the concept and emerging themes. Renewable & Sustainable Energy Reviews, 141, 110770. https://doi.org/10.1016/j.rser.2021.110770

Hansen, U., Pedersen, M. B., & Nygaard, I. (2015a). Review of solar PV policies, interventions and diffusion in East Africa. Renewable & Sustainable Energy Reviews, 46, 236–248. https://doi.org/10.1016/j.rser.2015.02.046

Holstenkamp, L. (2019). What do we know about cooperative sustainable electrification in the global South? A synthesis of the literature and refined social-ecological systems framework. Renewable & Sustainable Energy Reviews, 109, 307–320. https://doi.org/10.1016/j.rser.2019.04.047

Huber, S., & Steininger, K. W. (2022). Critical sustainability issues in the production of wind and solar electricity generation as well as storage facilities and possible solutions. Journal of Cleaner Production, 339, 130720. https://doi.org/10.1016/j.jclepro.2022.130720

HYPOSO. (n.d.). Uganda - HYPOSO: Hydropower solutions for developing and emerging countries - HYPOSO: Hydropower solutions for developing and emerging countries. https://www.hyposo.eu/en/hyposo-map/uganda/

IEA. (2022). Clean Energy Transitions in the Greater Horn of Africa. In iea.org. https://www.iea.org/reports/clean-energy-transitions-in-the-greater-horn-of-africa

Independent. (2023, July 20). TotalEnergies starts drilling in Murchison Park. The Independent Uganda: https://www.independent.co.ug/totalenergies-starts-drilling-in-murchison-park/

IRENA. (2021). Renewable Energy Policy for Cities: Experiences in Uganda. In irena.org.

Jefferson, M. (2008). Accelerating the transition to sustainable energy systems. Energy Policy, 36(11), 4116–4125. https://doi.org/10.1016/j.enpol.2008.06.020

Johnson, D., Horton, E., Mulcahy, R., & Foth, M. (2017). Gamification and serious games within the domain of domestic energy consumption: A systematic review. Renewable & Sustainable Energy Reviews, 73, 249–264. https://doi.org/10.1016/j.rser.2017.01.134

Kahunzire, A. E., Mahlooji, M., & Madani, K. (2020). Beyond Carbon Emissions: A System of Systems Approach to Sustainable Energy Development in East Africa. Springer eBooks, 323–349. https://doi.org/10.1007/978-3-030-40052-1_15

Kazibwe, K. (2023). Half of electricity produced in Uganda remains unused, says gov't. Nile Post. https://nilepost.co.ug/2023/07/05/half-of-electricity-produced-in-uganda-remains-unused-says-govt/

Khadam, A. M. A., Ramadan, K., & Hamouda, E. A. (2016). The establishment of electricity market structure in East African countries. 2016 Conference of Basic Sciences and Engineering Studies (SGCAC). https://doi.org/10.1109/sgcac.2016.7458007

Kinally, C., Antonanzas-Torres, F., Podd, F., & Gallego-Schmid, A. (2022). Off-grid solar waste in sub-Saharan Africa: Market dynamics, barriers to sustainability, and circular economy solutions. Energy for Sustainable Development, 70, 415–429. https://doi.org/10.1016/j.esd.2022.08.014

Kiprotich, N., De Dieu Hakizimana, J., & Chambile, E. (2021). Exploring Implication of Renewable Energy Transition on the Cost of Electricity and Green House Gases Emission in East African Countries. 2021 IEEE Southern Power Electronics Conference (SPEC). https://doi.org/10.1109/spec52827.2021.9709309

Kirubi, C., Jacobson, A., Kammen, D. M., & Mills, A. (2009). Community-Based Electric Micro-Grids Can Contribute to Rural Development: Evidence from Kenya. World Development, 37(7), 1208–1221. https://doi.org/10.1016/j.worlddev.2008.11.005

KIS. (n.d.). KIS - Kalangala Infrastructure Services Ltd. https://www.kis.co.ug/pages/view-page/Power-Services

Kovacic, Z., Musango, J. K., Buyana, K., Ambole, A., Smit, S., Mwau, B., Ogot, M., Lwasa, S., & Brent, A. C. (2021). Building capacity towards what? Proposing a framework for the analysis of energy transition governance in the context of urban informality in Sub-Saharan Africa. Local Environment, 26(3), 364–378. https://doi.org/10.1080/13549839.2020.1849075

Kumar, A., Sah, B., Singh, A., Deng, Y., He, X., Kumar, P., & Bansal, R. C. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renewable & Sustainable Energy Reviews, 69, 596–609. https://doi.org/10.1016/j.rser.2016.11.191

Kyeyune, H. (2023, March 9). Uganda announces plans to start nuclear power generation. AA. https://www.aa.com.tr/en/africa/uganda-announces-plans-to-start-nuclear-power-generation/2841543

Lahimer, A. A., Alghoul, M. A., Yousif, F., Razykov, T. M., Amin, N., & Sopian, K. (2013). Research and development aspects on decentralized electrification options for rural household. Renewable & Sustainable Energy Reviews, 24, 314–324. https://doi.org/10.1016/j.rser.2013.03.057

Lo, K. B., & Kibalya, B. (2023). Electric cooperatives and the political economy of rural electrification in Africa: Insights from Uganda. The Electricity Journal, 36(1), 107238. https://doi.org/10.1016/j.tej.2023.107238

Lyu, Y., Ali, S. F., Yin, W., & Kouser, R. (2022). Energy Transition, Sustainable Development Opportunities, and Carbon Emissions Mitigation: Is the Developed World Converging Toward SDGs-2030? Frontiers in Environmental Science, 10. https://doi.org/10.3389/fenvs.2022.912479

Mabea, G. A. (2020). Electricity market coupling and investment in renewable energy: East Africa Community power markets. International Journal of Sustainable Energy, 39(4), 321–334. https://doi.org/10.1080/14786451.2019.1709461

Madriz-Vargas, R., Bruce, A., & Watt, M. (2018). The future of Community Renewable Energy for electricity access in rural Central America. Energy Research and Social Science, 35, 118–131. https://doi.org/10.1016/j.erss.2017.10.015

Mamadouh, V., De Jong, M., & Lalenis, K. (2002). An introduction to institutional transplantation. In The Geojournal library (pp. 1–16). https://doi.org/10.1007/978-94-011-0001-4_1

Mandelli, S., Barbieri, J., Mereu, R., & Colombo, E. (2016). Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review. Renewable & Sustainable Energy Reviews, 58, 1621–1646. https://doi.org/10.1016/j.rser.2015.12.338

Manirambona, E., Talai, S. M., & Kimutai, S. K. (2022). A review of sustainable planning of Burundian energy sector in East Africa. Energy Strategy Reviews, 43, 100927. https://doi.org/10.1016/j.esr.2022.100927

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. Research Policy, 41(6), 955–967. https://doi.org/10.1016/j.respol.2012.02.013

Mbabazi, H. (2023, February 17). Power Distributor "WENRECo" Unveils High-Tech Contact Center For Better Customer Support - Thecapitaltimes. Thecapitaltimes. https://thecapitaltimes.co.ug/2023/02/17/power-distributor-wenreco-unveils-high-tech-contact-center-for-better-customer-support/

McGookin, C., Gallachóir, B. Ó., & Byrne, E. P. (2021). Participatory methods in energy system modelling and planning – A review. Renewable & Sustainable Energy Reviews, 151, 111504. https://doi.org/10.1016/j.rser.2021.111504

Mechtenberg, A. R., Borchers, K., Miyingo, E., Hormasji, F., Hariharan, A., Makanda, J., & Musaazi, M. K. (2012). Human power (HP) as a viable electricity portfolio option below 20W/Capita. Energy for Sustainable Development, 16(2), 125–145. https://doi.org/10.1016/j.esd.2011.12.006

MEMD. (2013). *Rural Electrification Strategy and Plan: Covering the Period 2013-2022*.

MEMD. (2023). Energy Policy for Uganda 2023.

Micheal, M., Yu, H., Cheng, S., Yrausquin, E. P., & Arnaud, K. L. (2018). Uganda's Energy Security Based on Prospects, Challenges, Opportunities, Supply, and Demand towards Achieving a Green Energy-Reliant Environment. International Journal of Energy Engineering, 8(2), 40–51. http://www.sapub.org/global/showpaperpdf.aspx?doi=10.5923/j.ijee.20180802.03

Mokveld, K., & Von Eije, S. (2018). Final Report Uganda. In https://www.rvo.nl/. https://www.rvo.nl/sites/default/files/2019/02/Final-Energy-report-Uganda.pdf

Muchunku, C., Ulsrud, K., Palit, D., & Jonker-Klunne, W. (2018). Diffusion of solar PV in East Africa: What can be learned from private sector delivery models? Wiley Interdisciplinary Reviews: Energy and Environment, 7(3). https://doi.org/10.1002/wene.282

Mugisha, J., Ratemo, M. A., Keza, B. C. B., & Kahveci, H. (2021). Assessing the opportunities and challenges facing the development of off-grid solar systems in Eastern Africa: The cases of Kenya, Ethiopia, and Rwanda. Energy Policy, 150, 112131. https://doi.org/10.1016/j.enpol.2020.112131

Murphy, J. D. (2001). Making the energy transition in rural east Africa: Is leapfrogging an alternative? Technological Forecasting and Social Change, 68(2), 173–193. https://doi.org/10.1016/s0040-1625(99)00091-8

Musisi, F., & Owiny, T. J. (2022, December 19). Karuma dam nears light at the end of dark tunnel. Monitor. https://www.monitor.co.ug/uganda/special-reports/karuma-dam-nears-light-at-the-end-of-dark-tunnel-4059782

Mwampamba, T. H., Owen, M., & Pigaht, M. (2013). Opportunities, challenges and way forward for the charcoal briquette industry in Sub-Saharan Africa. Energy for Sustainable Development, 17(2), 158–170. https://doi.org/10.1016/j.esd.2012.10.006

Mwirigi, C. (2021, December 9). Uganda turns to solar mini-grids to level-up its northern region. Pv Magazine International. https://www.pv-magazine.com/2021/12/09/uganda-turns-to-solar-mini-grids-to-level-up-its-northern-region/

Mwirigi, J., Makenzi, P. M., & Ochola, W. (2009). Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya. Energy for Sustainable Development, 13(2), 106–115. https://doi.org/10.1016/j.esd.2009.05.002

Nabielek, P., Dumke, H., & Weninger, K. (2018). Balanced renewable energy scenarios: a method for making spatial decisions despite insufficient data, illustrated by a case study of the Vorderland-Feldkirch Region, Vorarlberg, Austria. Energy, Sustainability and Society, 8(1). https://doi.org/10.1186/s13705-017-0144-x

Nafuna, S. (n.d.). Uganda's Policy on Energy and Power [Slide show]. https://eneken.ieej.or.jp/data/5041.pdf

Nakaweesi, D. (2022, February 9). Govt paying Shs87.7b for unused electricity. Monitor. https://www.monitor.co.ug/uganda/business/technology/govt-paying-shs87-7b-for-unused-electricity--3709992

Ndyabawe, K., & Kisaalita, W. S. (2014). Validity of the Africa-wide Lang factor of 2.63 for estimating small biogas plant installation costs in Uganda. International Journal of Agricultural and Biological Engineering, 7(1), 70–76. https://doi.org/10.25165/ijabe.v7i1.880

NEA & IAEA. (n.d.). IUREP Orientation Phase Mission Summary Report Uganda.

Nexus Game - Face the complexity of water-food-energy management. (2021, October 6). Nexus Game. https://nexus.socialsimulations.org/?_ga=2.20087551.658776747.1684762305-608864397.1683810381&_gl=1%2Aoczvsu%2A_ga%2ANjA4ODY0Mzk3LjE2ODM4MTAzODE.%2A_ga_2N5PHNFQV0%2AMTY4NDc2NjQ2Mi45LjEuMTY4NDc2NjQ5OS4wLjAuMA.

Ondraczek, J. (2013). The sun rises in the east (of Africa): A comparison of the development and status of solar energy markets in Kenya and Tanzania. Energy Policy, 56, 407–417. https://doi.org/10.1016/j.enpol.2013.01.007

Pandiyan, P., Sitharthan, R., Saravanan, S., Prabaharan, N., Tiwari, M. R., Chinnadurai, T., Yuvaraj, T., & Devabalaji, K. (2022). A comprehensive review of the prospects for rural electrification using stand-alone and hybrid energy technologies. Sustainable Energy Technologies and Assessments, 52, 102155. https://doi.org/10.1016/j.seta.2022.102155

Pascoe, R. (2022, February 4). A lot of hot air? Controversy grows about wind turbines' impact on health - DutchNews.nl. DutchNews.nl. https://www.dutchnews.nl/2022/02/a-lot-of-hot-air-controversy-grows-about-wind-turbines-impact-on-health/

PAU. (2023). Uganda's Petroleum Resources – Petroleum Authority of Uganda (PAU). https://pau.go.ug/ugandas-petroleum-resources/#

PROBICOU), Tumwesigye, R., Twebaze, P., Makuregye, N., & Muyambi, E. (2011). Key issues in Uganda's energy sector.

Project Drawdown. (2023, February 27). Small Hydropower | Project drawdown. https://drawdown.org/solutions/small-hydropower

Punys, P., Vyčienė, G., Jurevičius, L., & Kvaraciejus, A. (2023). Small hydropower assessment of Uganda based on multisource geospatial data. Water, 15(11), 2051. https://doi.org/10.3390/w15112051

REP. (2007). The Renewable Energy Policy for Uganda.

Reporter, I. (2021, March 9). UEDCL takes over Bundibugyo Electricity Generation Company. The Independent Uganda: https://www.independent.co.ug/uedcl-takes-over-bundibugyo-electricity-generation-company/

Reuters. (2023, March 9). Uganda plans to start nuclear power generation by 2031 - minister. Reuters. https://www.reuters.com/world/africa/uganda-plans-start-nuclear-power-generation-by-2031-minister-2023-03-09/

Roopnarain, A., & Adeleke, R. (2017). Current status, hurdles and future prospects of biogas digestion technology in Africa. Renewable & Sustainable Energy Reviews, 67, 1162–1179. https://doi.org/10.1016/j.rser.2016.09.087

Rossano, V., Roselli, T., & Calvano, G. (2017). A serious game to promote environmental attitude. In Smart innovation, systems and technologies (pp. 48–55). https://doi.org/10.1007/978-3-319-59451-4_5

Savic, D., Morley, M. S., & Khoury, M. (2016). Serious gaming for water systems planning and management. Water, 8(10), 456. https://doi.org/10.3390/w8100456

Scholz, G.. (2006). Sustainable Energy Services - A new energy policy for Sida. 19. 14-16.

Silicon Canals. (2023, January 3). Dutch-based battery energy storage developer GIGA Storage gets funding from Rabobank | Silicon Canals. Silicon Canals. https://siliconcanals.com/news/startups/dutch-giga-storage-gets-funding/

Sohail, M., Afrouzi, H. N., Ahmed, J., Mehranzamir, K., Tabassum, M., & Siddique, B. M. (2022). A comprehensive scientometric analysis on hybrid renewable energy systems in developing regions of the world. Results in Engineering, 16, 100481. https://doi.org/10.1016/j.rineng.2022.100481

Solargis. (n.d.). Global Solar Atlas. The World Bank Group. https://globalsolaratlas.info/map?r=UGA&c=1.439058,32.497559,7

Stanitsas, M., Kirytopoulos, K., & Vareilles, É. (2019). Facilitating sustainability transition through serious games: A systematic literature review. Journal of Cleaner Production, 208, 924–936. https://doi.org/10.1016/j.jclepro.2018.10.157

Stojanovski, O., Thurber, M. C., & Wolak, F. A. (2017). Rural energy access through solar home systems: Use patterns and opportunities for improvement. Energy for Sustainable Development, 37, 33–50. https://doi.org/10.1016/j.esd.2016.11.003

Stritzke, S., Trotter, P. A., & Twesigye, P. (2021). Towards responsive energy governance: Lessons from a holistic analysis of energy access in Uganda and Zambia. Energy Policy, 148, 111934. https://doi.org/10.1016/j.enpol.2020.111934

Thomas, M., Partridge, T., Pidgeon, N. F., Harthorn, B. H., Demski, C., & Hasell, A. (2018). Using role play to explore energy perceptions in the United States and United Kingdom. Energy Research and Social Science, 45, 363–373. https://doi.org/10.1016/j.erss.2018.06.026

Times, N. (2021, August 14). Fleet of over 50 fishing boats take to the Ijsselmeer in protest of wind farms. NL Times. https://nltimes.nl/2021/08/14/fleet-50-fishing-boats-take-ijsselmeer-protest-wind-farms

Times, N. (2022, August 5). New energy contract €4,000 more expensive than a year ago. NL Times. https://nltimes.nl/2022/08/05/new-energy-contract-eu4000-expensive-year-ago

Trotter, P. A., & Maconachie, R. (2018). Populism, post-truth politics and the failure to deceive the public in Uganda’s energy debate. Energy Research and Social Science, 43, 61–76. https://doi.org/10.1016/j.erss.2018.05.020

Turnheim, B., Berkhout, F., Geels, F. W., Hof, A. F., McMeekin, A., Nykvist, B., & Van Vuuren, D. (2015). Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges. Global Environmental Change-human and Policy Dimensions, 35, 239–253. https://doi.org/10.1016/j.gloenvcha.2015.08.010

Twesigye, P. (2022). Why merging Uganda's electricity sector agencies is a bad idea. The Conversation. https://theconversation.com/why-merging-ugandas-electricity-sector-agencies-is-a-bad-idea-170968

UBC Television Uganda. (2023, July 4). UEDCL TAKES OVER OPERARTIONS OF PACMECS [Video]. YouTube. https://www.youtube.com/watch?v=iSRxrXW5o0Q

UEGCL. (2018). UEGCL Strategic Plan 2018-2023 (uegcl.com). https://www.uegcl.com/publications/strategic-plan-and-directions/

Uganda Energy Situation - energypedia. (n.d.). https://energypedia.info/wiki/Uganda_Energy_Situation#Energy_situation

UNSDG. (2022, November 9). Energy - UNSDG. United Nations Sustainable Development. https://www.un.org/sustainabledevelopment/energy/

USAID. (n.d.). What are the technical components of a mini-grid? usaid.gov. https://www.usaid.gov/energy/mini-grids/technical-design/components#:~:text=A%20mini%2Dgrid's%20production%20system,provide%20electricity%20to%20end%20users.

Van Eijck, J. J., & Romijn, H. H. (2008). Prospects for Jatropha biofuels in Tanzania: An analysis with Strategic Niche Management. Energy Policy, 36(1), 311–325. https://doi.org/10.1016/j.enpol.2007.09.016

Wabukala, B. M., Bergland, O., Rudaheranwa, N., Watundu, S., Adaramola, M. S., Ngoma, M., & Rwaheru, A. A. (2022). Unbundling barriers to electricity security in Uganda: A review. Energy Strategy Reviews, 44, 100984. https://doi.org/10.1016/j.esr.2022.100984

Wagner, A., & Gałuszka, D. (2020). Let's play the future: Sociotechnical imaginaries, and energy transitions in serious digital games. Energy Research and Social Science, 70, 101674. https://doi.org/10.1016/j.erss.2020.101674

Walekhwa, P. N., Mugisha, J., & Drake, L. (2009). Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications. Energy Policy, 37(7), 2754–2762. https://doi.org/10.1016/j.enpol.2009.03.018

Wigley, R. (2023). Renewable Energy vs Sustainable Energy: What's the Difference? MA In Sustainable Energy. https://energy.sais.jhu.edu/articles/renewable-energy-vs-sustainable-energy/

Woolley, K. E., Bartington, S. E., Pope, F. D., Greenfield, S. M., Jowett, S., Muhizi, A., Mugabe, C., Ahishakiye, O., Thomas, G. N., & Kabera, T. (2022). Domestic fuel affordability and accessibility in urban Rwanda; policy lessons in a time of crisis? Energy for Sustainable Development, 71, 368–377. https://doi.org/10.1016/j.esd.2022.10.008

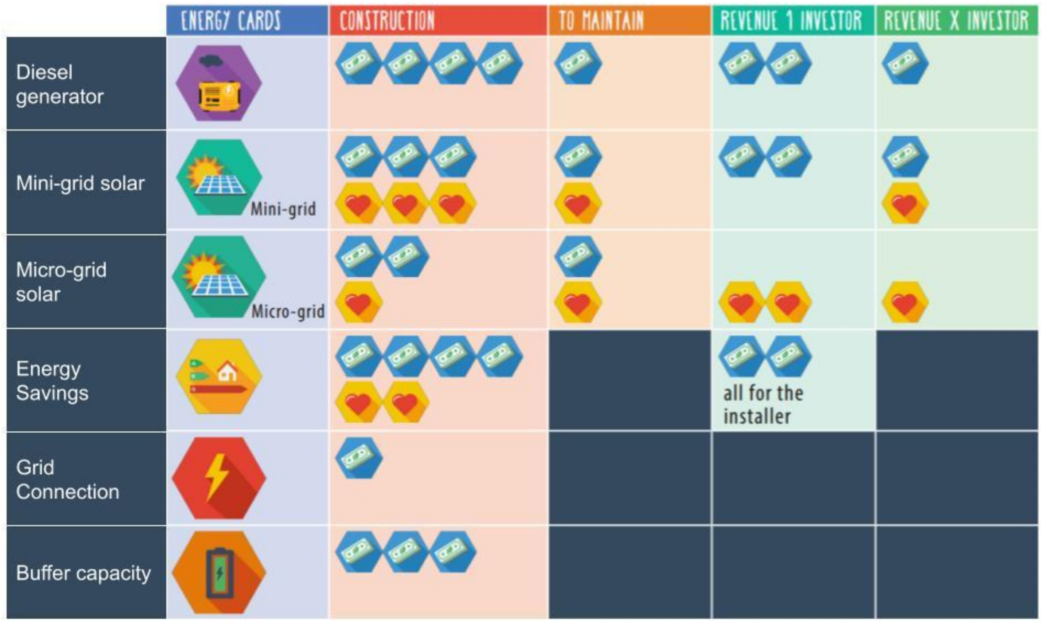
World Bank. (2015). Evaluation of Rural Electrification Concessions in sub -Saharan Africa Detailed Case Study: Uganda.

World Bank. (n.d.). Rural population (% of total population) - Uganda. Retrieved June 15, 2023, from https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=UG

Yadoo, A., & Cruickshank, H. (2010). The value of cooperatives in rural electrification. Energy Policy, 38(6), 2941–2947. https://doi.org/10.1016/j.enpol.2010.01.031

A. Game Appendix

A.1 Payment Schedule and Energy Map Key



A.2 Game Components and Relations

Policy Variables:

- Solar mini-grid and micro-grid farms
- Buffer Capacity
- Existing Diesel generators
- New grid connections for new farms
- REA subsidies
- Bank loans
- Sensitization campaigns
- Fines for failed objectives

Strategic Measures	Objectives	Roles
Reliable and sufficient energy supply	To supply 10 energy units each round	REA | LEC | Energy Companies
	To ensure sufficient grid and buffer capacity for all new farms	Grid Operator
Transition to sustainable energy	To save at least 8 energy units using solar energy or energy savings	REA | LEC
Profitability	To have the largest market share by owning the most energy units.	Energy Companies
	To be stakeholders in energy supply	Local Installer | Residents

A.3 Game Rules (Adjusted)

Checklist

Before playing, we recommend having the following numbers printed per game.

- 1x game rules in a ring binder – A5
- 1 x game manual in a ring binder – A5
- 1 x the 7 **role** cards – A5
- 8 x payment schedule – A5
- 1 x set of round cards (5 cards) – A5

Means of payment

- 3 x sheet with 16 hearts (48 hearts) – A4
- 1x sheet with 16 loans – A4
- 5 x the sheet with 16 Daalders (80 Daalders) – A4

Network management cards

- 30 x buffer capacity – A6
- 30 x sustainable connection – A6

Energy cards

- 8 x three forms of energy saving – A5
- 20 x micro-grid solar farm – A5 with cuts on two of the corners
- 20 x mini-grid solar farm – A5 with cuts on two of the corners
- 30 x diesel generators – A5

Initial situation Cards

- 1 x mini-grid **solar** farm initial situation – A5 with intersections on top right corner
- 9 x Diesel generators initial situation – A5

Also needed:

- 10 blue | red | yellow | green |purple chips
- Rubber bands | bags| box to sort and store the materials
- A timer

Power! The adaptation

Goal of the game

The Central Service Territory players must work together to sustainably supply energy to the region. The district has 10 villages, each supplied by ten energy units (EE). In 16 years (at the end of 4 rounds), 8 of these 10 EE must be sustainable. This can be done by building micro-grid or mini-grid solar farms or saving energy. This requires money (Daalders) and support (hearts).

In addition to the common goal, each player has personal objectives regarding sustainability, support, market share, security of supply and profit. The player who has achieved their goal at the end of the game has won, **but only when the common goal has also been achieved.**

Preparation for the game

As the game leader, take the time to properly the game. This way, you can help navigate the players through the game. Read all the game materials carefully in advance:

- This rule book
- The game manual
- The role cards
- The energy cards with costs and revenues.

Organising the game session

Playing the game, including the reflection, lasts about two and a half hours. So schedule plenty of time for the game session.

To play the game, at least 8 participants are required to play the following roles: Local energy cooperative (LEC), Rural Electrification Agency (REA), power company, renewable energy company, grid operator, local installer, residents and game leader.

- If there are more than 8 players, a role can be played by a 2-player team.
- Provide a space with a large table (1.5 x 2m) for players to easily walk around.

Preparation of the game

Sort the energy cards and place the diesel generators, grid cards, and solar farm cards face up in 3 piles on the table. Distribute 5 energy-saving cards among the roles:

- 2 property cards for local energy cooperative
- 2 property cards for the residents
- 1 municipal property card for REA

Place the remaining energy saving cards face down in a pile on the table. These come into play only when the local installer has achieved energy savings at 1 of the players.

Sort the payment cards and place them in 2 stacks with the image side up.

Prepare the playing field as shown below. Place the power company token on the diesel generators and the cooperative and renewable energy company tokens on the solar farm.

Set a timer. For example, this could be your mobile phone.
Place the role cards face up. Place the starting amount on each role card.

Assign the roles. This can be done by chance by having the players draw a role card or based on preference (“Who wants to play…?”).

Take the binder with game leader cards. This has written down what the game leader must say and do during the game. Start by reading the introduction note.

The Game starts

The game leader introduces the game. The game consists of 4 rounds, each representing four years. **Each round consists of 5 different phases.**

Phase 1: The News

There is news in the region. The game leader reads the news report belonging to the round. This news report shows what is happening in the region and what the players should consider in the coming round. Play well to the event to keep the residents of the Central Service Territory happy. This will help you further in the game.

If you fail and the residents are dissatisfied. This has negative consequences for the players.

Phase 2: Prepare electricity grid

5 minutes

The current electricity grid needs to be updated to have sufficient capacity to include energy generated from fluctuating sources like solar.

Renewable Energy Company	2 Hearts, 2 Daalders
Power Company	5 Daalders
REA	1 Heart, 1 Daalder
Local Energy Cooperative	4 Hearts
Local Installer	2 Daalders
Grid Operator	2 Daalders
Residents	1 daalder

The grid operator is in charge of preparing the grid for renewable energy and other energy sources. In doing so, they may consult with the other players. The other players can co-invest in new connections and buffer capacity.

The grid operator performs the following 2 steps:

1. **Inventory of required grid capacity**. The grid operator asks each player what they want to build in the next round. The players answer briefly with their ambition.
2. **Preparing the grid.** The grid operator has to choose from the following 2 options:

Building sustainable connections. Based on the requirements of the other players, the grid operator can expand the grid to connect the new generation plants to the grid. To prevent blackouts, generation plants can only be built on slots with a new connection (see p. 8).

Building buffer capacity. Solar farms produce different amounts of energy all the time. Sufficient buffer capacity must be available to absorb peaks and troughs in the energy supply. Diesel generators provide buffer capacity, which can be increased by building new storage. These cards have a battery icon in the top right corner. To avoid blackouts, there should be as many batteries as solar farms on the playing field (see p. 8).

Example: How do you put connections and buffer capacity?

Place durable connections (red) at the bottom of the box.

Place buffer capacity cards (orange) above that, as shown in the figure. In the next phase, the energy cards are on top of the connection and buffer cards.

PHASE 3: NEGOTIATING

10 minutes

Build new energy facilities, maintain existing ones or save energy. Engage with your fellow players and negotiate who pays for what. **You can buy energy cards from the bank, which the game leader plays.**

Note! First come, first served. So buy energy cards quickly.

In this phase, players have a choice of 2 options:

a) Maintain existing energy by attaching the same energy card to an energy card that was placed on the playing field in the previous round.

b) Investing in new energy facilities or savings by adding a different energy card. Placing a card in a space is also considered a new investment.

On the energy cards, you can see how much each investment yields. When you invest with several parties, you have to share the income, and you earn less per player than when you invest alone.

Investing in energy cards makes you a shareholder of the energy supply. Place the energy card you bought on the playing field and place your token on the card. On this basis, you will be paid out.

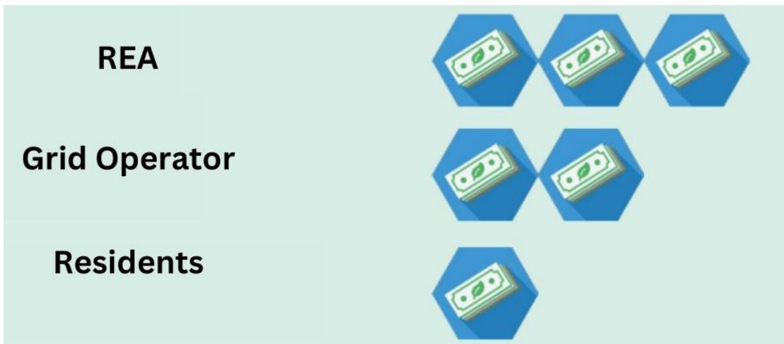
Note! Only some players can get shares in an energy supply. REA and the grid operator are public organisations. They can only give subsidies and never get revenue from energy cards.

PHASE 4: PAYOUT

The game leader also plays the bank and must pay the players fixed and variable revenues.

Fixed income

The following players receive income for their operations.



Variable revenue

All players, except REA and the grid operator, are paid on the basis of shares (chips) in energy cards. The energy cards state how much each investor receives.

PHASE 5: REFLECTION

Reflect on what happened in the last round. Are there fines or rewards?

Blackout

Check whether the CST is without power. A blackout occurs when one or more of the following situations has arisen. In these cases, either the grid operator and/or energy suppliers are fined.

Situation 1: Not enough energy has been supplied.
The CST needs 10 energy units each round to meet its energy demand at the end of the 16 years. If fewer than 10 energy cards have been placed on the playing field, then the region will have an energy shortage.

Example energy shortage

There are 9 energy cards on the playing field this round. There is one energy unit less supplied by the energy suppliers. This caused a complete blackout in the region

The following players will be fined because they are obliged to provide sufficient energy: The renewable energy company, the power company and the local energy cooperative.

Renewable Energy Company	Subtract 2 Daalders
Energy Company	Subtract 2 Daalders
Local Energy Cooperative	Subtract 2 Daalders

No *Daalders*? The fine can also be paid in hearts.

Situation 2: Insufficient new connections

The electricity grid needs to be upgraded to connect the new generation plants. New plants built on a space without a grid are not connected to the electricity grid, and therefore the energy generated by these farms is not supplied to the region. This creates an energy shortage.
It is the responsibility of the grid operator to build enough connections. The grid operator will be fined a penalty for the round if there are insufficient connections:

Grid Operator	Subtract 1 Daalder

Situation 3: Insufficient Buffer Capacity
Solar farms depend on weather conditions and therefore do not supply constant energy. Buffer capacity is needed to absorb peaks and troughs in the energy supply. Buffer

capacity is provided by either diesel generators or energy storage. A battery icon in the top right corner represents energy storage.

If there are more renewable energy sources than buffer capacity in a round, an imbalance will arise in the grid, leaving residents in the dark. The grid operator is responsible for keeping an eye on the buffer capacity. The grid operator will be fined for an imbalance.

Grid Operator	Subtract 1 Daalder

NB! If both situations 2 and 3 occur, then both fines are added together.

Example balance on the electricity grid

In the example above, there is balance.

Sufficient connections

The 2 solar micro-grid farms and 4 wind farms are built on a square with extra grid capacity, which can be seen by the red electricity icon at the bottom left.

Sufficient buffer capacity

There is also sufficient buffer capacity for the 6 sustainable energy parks because there are 6 buffer facilities on the table (3 diesel generators + 3 extra buffer capacities), as can be seen from the orange battery icon at the right.

Example imbalance on the electricity grid

In the example below, there is an imbalance.

Too few connections

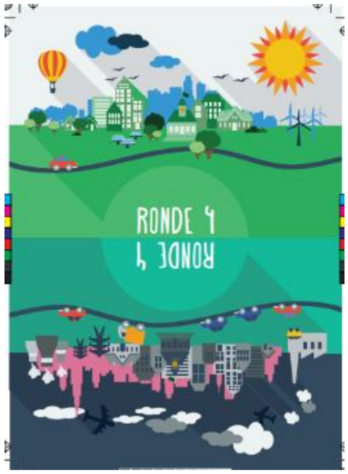
The solar parks are built on a square without extra grid capacity; the bottom left corner is empty. As a result, they cannot supply energy to the grid.

Too little buffer capacity

In addition, only 3 battery icons are on the table (the 3 diesel generators). At the same time, 6 units of buffer capacity are needed to absorb the energy peaks and troughs of the solar parks and 4 wind farms. Because, in this example, there are both too few connections and too little buffer capacity, the grid operator will receive a fine of 2 Daalders in this case.

Figure 17: Sufficient connections

NB! Wind farms will be replaced by mini-grid solar farms and coal power plants by diesel generators.



Are the citizens satisfied? Then the round card can remain with the white picture at the top.

Are citizens dissatisfied? Turn the round card with the dark side up.

End of the game

The game ends after the payout phase of round 4. Players win when they have managed to make 8 energy units more sustainable. The player who also achieved their personal goals is the winner of the game. After the game, there is a reflection on the course of the game and what the players can learn from this for practice.

For the Game Leader: Intervening during the game

Because the game is played differently every time, the game may seem to freeze. Should this happen, the game leader can take the following actions to stimulate the game.

Situation 1: No more money is in circulation, not even by exchanging hearts for Daalders. A round is imminent in which no energy can be built or maintained.

Action: “CST is in trouble.”
In order to still be able to supply energy, an emergency fund of 8 Daalders has been provided from government roads. REA manages this emergency fund.

Situation 2: No more hearts are in circulation, not even by exchanging Daalders for hearts. A round is imminent in which nothing can be built that requires hearts.

Action: the same as in situation 1. With the extra hearts instead of Daalders got from the bank.

Situation 3: Sustainability does not get going (Not likely to occur)
There is a large share of diesel generators on the playing field. In this case, the energy company will probably maintain its position.

Action: An optional news item is added at the end of round 3. If seven or more diesel generators are on the playing field, you can read the extra news item. The game leader automatically encounters this moment in the game manual.

A.4 Role Cards (Adjusted)

You play the renewable energy company.

You may share the information on this card with other players as you see fit.

Goals for the next 16 years:

Security of supply: Together with the other energy suppliers, supply enough energy units (10 EE) each round to meet the energy demand of CST residents.

Sustainability: Make at least 8 EE sustainable by building micro and/or mini-grid solar farms.

Market share: Capture as much market share of the energy supply as possible. End the game with at least 4 solar farms that belong to your company alone.

You have the following resources at your disposal for this:

	At the beginning of the game, you co-own one solar mini-grid together with the Local Energy Cooperative.
Starting Amount	2 Daalders 2 Hearts
Variable Income	Based on shares in energy cards Based on event cards
Exchange rate	You can exchange Daalders and hearts at the bank at an exchange rate of 3:1

You play the power company.

You may share the information on this card with other players as you see fit.

Goals for the next 16 years:

Security of supply: Together with the other energy suppliers, supply enough energy units (10 EE) each round to meet the energy demand of CST residents.

Market share: Maintain as large a market share of energy supply in the region as possible. End the game with at least 5 diesel generators and/or solar farms that are yours alone.

Image: Create a positive image of your company. Finish the game with at least 5 hearts.

You have the following resources at your disposal for this:

	At the beginning of the game, you own 9 Diesel generators.
Starting Amount	5 Daalders
Variable Income	Based on shares in energy cards Based on event cards
	You can borrow a maximum of 5 Daalders each round from the bank. You must repay these at the beginning of each new round.
Exchange rate	You can exchange Daalders and hearts at the bank at an exchange rate of 3:1

Tip! Use your Daalders as a marketing budget and buy hearts at the bank at the exchange rate of 3:1

You play the Rural Electrification Agency.

You may share the information on this card with other players as you see fit.

Goals for the next 16 years:

Sustainability: Achieve the Sustainable Electrification Agreement targets. Ensure at least 8 energy units (EE) are generated by solar farms or saved.

Satisfied citizens: Watch the CST EYE news reports, and respond well to the events in the region.

You have the following resources at your disposal for this:

Starting Amount	1 Heart, 1 Daalder
Fixed Income	3 Daalders
Variable Income	Based on event cards
Energy Saving	1 EE savings potential. Engage the local installer to make your municipal property energy efficient.
Exchange rate	You can exchange Daalders and hearts at the bank at an exchange rate of 3:1

Note! As REA, you can only grant subsidies to energy projects. Therefore you never receive income from energy cards.

You play the Local Energy Cooperation.

You may share the information on this card with other players as you see fit.

Goals for the next 16 years:

Security of supply: Together with the other energy suppliers, supply enough energy units (10 EE) each round to meet the energy demand of CST residents.

Sustainability: Make at least 9 EE sustainable by building micro and/or mini-grid solar farms or saving energy.

Social Support: Keep the members of your cooperative happy. Realise 3 EE renewable energy before the end of round 2.

You have the following resources at your disposal for this:

	At the beginning of the game, you co-own one solar mini-grid together with the renewable energy company.
Starting Amount	4 hearts
Variable Income	Based on shares in solar parks Based on event cards
Energy Saving Potential	2 EE savings potential. Engage the local installer to make members' homes energy efficient.
Exchange rate	You can exchange Daalders and hearts at the bank at an exchange rate of 3:1

Tip! Use the support of your members to bring in investments. Exchange hearts for Daalders at the exchange rate of 3:1

You play the local installer.

You may share the information on this card with other players as you see fit.

Goals for the next 16 years:

Profit: Make a profit by saving energy from players who own property in the region. End the game with 6 Daalders.

Explanation: *You invest in the resources needed to make a building energy efficient. The money the property owner saves on his energy bill is paid to you for the duration of the contract term.*

Profit: Make a profit by co-investing in micro and/or mini-grid solar farms. End the game with 6 Daalders.

You have the following resources at your disposal for this:

Starting Amount	2 Daalders
Variable Income	Based on energy-saving cards Based on shares in energy cards Based on event cards
Loan	Each round, you may borrow up to 4 Daalders from the bank. These loans are long-term and must be paid off at the end of round 4.
Exchange rate	You can exchange Daalders and hearts at the bank at an exchange rate of 3:1

Tip! Are you unable to get residents to use energy more consciously? Reach the people of the CST with a substantial marketing budget. Convert Daalders into hearts at the exchange rate of 3:1

You play the Grid Operator.

You may share the information on this card with other players as you see fit.

Goals for the next 16 years:

Security of supply: Ensure that new solar farms can be connected to the electricity grid. Provide at least 8 new renewable connections. Only on squares with this connection can new solar farms be built. Solar farms on a square without a sustainable connection? Then there is a black-out, and you will be fined 1 Daalder.

Security of supply: Absorb peaks and troughs in the energy supply from solar farms by ensuring sufficient buffer capacity. Diesel generators and storage units provide buffer capacity. Buffer capacity should always equal or exceed the number of solar farms to avoid a blackout. More solar farms than buffer capacity (= the number of orange batteries)? Then a blackout occurs, and you will be fined 1 Daalder.

You have the following means at your disposal:

Starting Amount	2 Daalders
Fixed Income	2 Daalders
Variable Income	Based on event cards

Note! As a grid operator, you do not have the authority to invest in energy or other commercial activities. Therefore, you never receive returns from energy cards.

You play the residents of the Central Service Territory (CST)

You may share the information on this card with other players as you see fit.

Goals for the next 16 years:

Image: Improve the image of the businesses that are part of your community. End the game with at least 5 hearts.

Sustainability: Make all your homes energy efficient. Save 2 energy units (EE).

Sustainability: Install solar panels on the roofs of your property. In doing so, become a (co-) shareholder in 3 micro-grids.

You have the following resources at your disposal for this:

Starting Amount	1 Daalder
Fixed Income	1 Daalders
Variable Income	Based on shares in solar parks Based on event cards
Energy Saving Potential	2 EE savings potential. Engage the local installer to make your households energy efficient.
Exchange rate	You can exchange Daalders and hearts at the bank at an exchange rate of 3:1

A.5 Game Leader's Manual (Adjusted)

Welcome to your role as the game leader

Congratulations on being chosen as the game leader!

Your task is to guide the players towards the full electrification of the Central Service Territory (CST).

Fortunately, you won't be alone in this endeavour. This booklet describes everything you need to say or do during the game.

So, follow this booklet and lead the players to a sustainably electrified CST!

[Turn the page. Text in square brackets indicates an action you don't need to read out loud.]

Aim of the game
Welcome everyone! We are about to play a game to gain insights into how a changing energy world works.

You must all work towards supplying the full energy demand of the Central Service Territory or CST.

Each of you has a specific role to play. You will always have to weigh between your interests and the common goal, namely sustainable energy production and the well-being of the residents of CST.
Afterwards, we will talk about this dynamic energy system and the role you all can play in it now and in the future.
Let's get started!

Welcome to the Central Service Territory (CST)!
The members of CST have the ambition to electrify their communities and do so sustainably. To achieve this, the local energy cooperative, in consultation with the Rural Electrification Agency (REA) and the business community, signed a Sustainable Electrification Agreement for the next 16 years.

This agreement aims to generate or save 8 units of renewable energy compared to the current situation in which the region is supplied by costly and polluting diesel generators. The agreement has received much media attention, and the media will closely follow the progress in CST. It is now up to you, the local players, to show that achieving these ambitious goals in practice is possible.

How do you win the game?
The region consists of 10 villages mainly supplied energy by diesel generators that are owned by the power company. In order to reach the target set in the agreement, a total of 8 villages will have to be made sustainable. This can be done by building mini-grid or microgrid solar farms or saving energy.

Fortunately, a local energy cooperative has just been established and has built one solar mini-grid with the renewable energy company in one village. This leaves only 7 villages to be converted in order to win the game.

The player who additionally achieves their personal goals is the ultimate winner of the game.

Introductions

You have all been given a role card describing the part you play in realising the Sustainable Electrification Agreement. Please read this card carefully now. [Wait five minutes, or until everyone has finished reading]

Let's start with a brief introduction based on your role card. You can decide what to share about your role, for example, who you are, and what you hope to achieve in the near future.

[Briefly give each party the floor]

The flow of the game

We will play four rounds of four years each. Each round consists of five phases, which I will briefly describe before we start.

Phase 1: The CST Eye

Each round, except for round one, begins with a local news item from the CST Eye. Pay attention, because this news will make clear what you need to consider in the upcoming round, and what the implications might be.

Phase 2: Prepare the electrical grid

In the 2^{nd} phase, the ball is in the grid operator's court. They must prepare the electricity grid for the arrival of new energy plants. First, they inventory which energy facilities the other players would like to build in the next round. They then build the necessary connections and buffer capacity. **This round lasts 5 minutes.** Note! Time goes faster than you think.

Phase 3: Negotiate

Build new energy systems, maintain the existing ones, or save energy. Negotiate with your fellow players about who pays for what. You can buy energy cards from the bank, which is played by me.

Attention! First come, first served. So don't wait too long to buy energy cards.

This phase last 10 minutes, and you have two options in this phase:

a) Maintain existing energy supplies by adding the same energy card to an energy card already on the playing field [You may illustrate]

b) Invest in new energy facilities or savings by adding another energy card to a card already on the playing field or an empty space. Both cases are considered investments.
[You may illustrate]

On the energy cards, you can see how much each investment yields. When you invest with multiple parties, you have to share the income and earn less per player than when you invest alone.

Investing in energy cards makes you a shareholder in the energy supply. Place your token on the card. You will be paid based on this.

Phase 4: Payout

In phase 4, everyone is paid. Your role card shows how much you will receive as fixed income and whether you may receive income from investments.

Note! Fines may also be handed out if you have neglected your duties. I, therefore, ask the following questions each round:

Have energy suppliers met the energy demand?
There must be 10 cards on the playing field each round to avoid a blackout.

Did the grid operator provide sufficient grid capacity?

New energy plants cannot be built on a square without a sustainable connection. If they do, a blackout occurs. (see page 8 in the rulebook for more explanation.)

In addition, there cannot be more solar farms on the playing field than the number of units of buffer capacity. The buffer capacity is represented by a battery icon in the upper right corner. (see page 8 in the rulebook for more explanation.)

[If there are questions about this, you can answer them. Also, emphasise that this will become clearer during the game play]

Phase 5: Reflection

In the final stage, we reflect on the news report and whether the residents of CST are satisfied with what has happened in their community. Will you receive either a reward or a fine?

In addition, in each round, 1 player will come forward and share how they perceive the electrification process is progressing.

Means of payment

In the game, we pay with Daalders and hearts.

Hearts represent support. For example, whereas mini-grid solar is a sustainable form of energy, it may require larger land acquisition.

It is possible to convert Daalders into hearts and vice versa. On your role card is the exchange rate.

Let's start playing!

The mechanics of the game will become clearer as we go along.

On the table, you will see the four rounds and the 10 energy units currently being delivered to the region.

Round 1

There will be no news item in this round, so we first get a feel of the game's mechanics. Let's get straight to phase 2.

Round 1: Prepare the electrical grid **(5 minutes)**

This is up to the grid operator. What do you want to do this round? Let's look at the options:

1. Inventory of the required grid capacity. The grid operator asks all the parties what they'd like to build in the next round. The players answer briefly.
2. Preparing the grid
   - Building connections
   - Or building buffer capacity to accommodate peak and off-peak loads.

We'll briefly tour the other players: What do you expect to build in this round? You obviously can't know for sure yet. Each party may say in one or two sentences what their expectations are.
[Let each party speak briefly, and ask the grid operator to decide on what to construct]

Round 1: Negotiation

Now, you all get to work. You have **10 minutes** to decide which energy units to invest in. Your time starts NOW!
[set timer to 10 minutes]
[reminder after 5 minutes]
[announce last minute, count down last seconds]
[After 10 minutes]: Time is up! We are going to the payout phase!

[Optionally, the last energy cards may still be put down, but be strict: in the Real World, time is ticking too]

Round 1: Payout

Now to the payouts. I'll start with the fixed payouts:

Then, the investments, let's see who invested.
[Go through all the parties one by one and see what energy they have invested in. Pay everyone out loud]

Round 1: FINES?

Have energy suppliers met the energy demand?
There must be 10 cards on the playing field each round to avoid a blackout.
[Failed? The power company, the renewable energy company and the cooperative will each be fined 2 Daalders. If they do not have Daalders, the fine may also be paid in hearts. If they have no means of payment at all, they receive 2 loan cards from the bank. This must be paid off the next round].

Did the grid operator provide sufficient grid capacity?
Newly built solar farms cannot be built on a space without a sustainable connection.
[Are there generation units without a connection? Then a blackout occurs. The grid operator is fined 1 Daalder]

In addition, there cannot be more solar farms on the playing field than the number of units of buffer capacity. This buffer capacity is represented by a battery icon in the upper right corner.
[Count out loud the number of buffer units and the number of solar farms. More solar farms than buffer units? The peak and off-peak load cannot be absorbed by the grid. The grid operator is fined 1 Daalder. Add up both fines if necessary]

ROUND 1: Reflection

Questions to REA

- How are regional goals coming along?
- Are the residents of the CST satisfied?
- What should be different next round?

Before we start Round 2, I encourage everyone to read their role cards carefully.
[Wait a few minutes]

Round 2

The CST EYE News

Peaks and troughs threaten the energy supply!

The power grid is in worse shape than imagined; it must be renewed to ensure a stable electricity supply and accommodate the peaks and troughs of renewable energy. That is why REA, in collaboration with the grid operator, is starting a demonstration project around innovative buffer capacities such as energy storage and demand management. There is a grant party that will provide half of the financial cost for a new buffer capacity. This party still seeks **co-investors to provide buffer capacity to at least two villages.**

For this plan to succeed, one unit of buffer capacity will need to be funded this round. If successful, two units of buffer capacity can be built.
Round 2: Prepare the electrical grid
The grid operator is at it again: what do you want to do this round?

- Building connections
- Or building buffer capacity to accommodate peak and off-peak loads.

We do another quick tour of the other players: what do you expect to build in this round?
[Start the timer at 5 minutes]

[Let each party speak briefly, and ask the grid operator to decide on what to construct]

Round 2: Negotiation

Now you all get to work. You have 10 minutes to decide which energy units to invest in. Your time starts NOW!

[set timer to 10 minutes]

[reminder after 5 minutes]

[announce last minute, count down last seconds]

[After 10 minutes]: Time is up! We are going to the payout phase!

[Optionally, the last energy cards may still be put down, but be strict: in the Real World, time is ticking too]

Round 2: Payout

Now to the payouts. I'll start with the fixed payouts:

Then the investments, let's see who invested.

[Go through all the parties one by one and see what energy they have invested in. Pay everyone out loud]

Round 2: FINES?

Have energy suppliers met the energy demand?

There must be 10 cards on the playing field each round to avoid a blackout.

[Failed? The power company, the renewable energy company and the cooperative will each be fined 2 Daalders. If they do not have Daalders, the fine may also be paid in hearts.

If they have no means of payment at all, they receive 2 loan cards from the bank. This must be paid off the next round].

Did the grid operator provide sufficient grid capacity?

Newly built solar farms cannot be built on a space without a sustainable connection.

[Are there generation units without a connection? Then a blackout occurs. The grid operator is fined 1 Daalder]

In addition, there cannot be more solar farms on the playing field than the number of units of buffer capacity. This buffer capacity is represented by a battery icon in the upper right corner.
[Count out loud the number of buffer units and the number of solar farms. More solar farms than buffer units? The peak and off-peak load cannot be absorbed by the grid. The grid operator is fined 1 Daalder. Add up both fines if necessary]

Round 2: Reflection

At the beginning of this round, there was a news report about a demonstration project around innovative buffering capacity. How did this go?
[See if option 1 or option 2 applies and read the corresponding text]

1. REA have found enough investors for the demonstration project to provide two villages with buffer capacity. The households participating in the demonstration project are enthusiastic and feel committed to the cause, and the grid is better equipped for the future. All co-investors of this project deserve a heart. [Pay the hearts; turn the round card white side up].
2. REA did not find enough investors for the demonstration project. The grid is overloaded, and the grid operator must repair the damage. This cost the grid operator 2 Daalders. In addition, the residents were in the dark, and their trust in REA and the grid operator was damaged. Take the fine [Turn the round card dark side up]

Reflection Follow-up

In this round, we reflect with the grid operator

- How is the CST grid doing?
- Has it managed to accommodate the peaks and troughs of renewable energy?
- Will this become a problem in the future, do you think?
- What should be different for the next round?

[If necessary, help the grid operator explain the problems of the peaks and troughs of renewable energy and the importance of buffer capacity: storage and demand-side management].

ROUND 2: REFLECTION INTERIM OBJECTIVE

The cooperative has an intermediate goal on its role card. My question to the cooperative: Was it successful in achieving 3 renewable energy units?

[See if option 1 or option 2 applies and read the corresponding text]

1. Success. The members of the cooperative have become excited and engaged by this success. You may receive 3 hearts.
   [Pay hearts to the cooperative]
2. Failed? Cooperative members are losing confidence in your capabilities. You must turn in 3 hearts.
   [Take fine in receipt. Not enough hearts? The cooperative needs to borrow from the bank. Give the correct number of loan cards. These must be paid off at the end of the next round]

[ROUND 2: ADDITIONAL NEWS RELEASE]

[Read this news item only when there are currently 7 or more units of grey energy remaining]

Dear parties, something is happening, and an additional news release has been issued about it. Please listen carefully:

The polluter pays!

Climate change and fossil fuel extractions are causing more and more natural disasters, such as drastic changes in weather patterns, drops in water levels, floods and droughts in different areas.

It is clear to Ugandan politicians that something must be done now. A bill is underway to make grey energy producers pay a tax for emissions.
To get ahead of this sweeping bill, CST is setting an ultimatum: by the end of the next four years, at least 60% of energy must be generated sustainably.

If this does not succeed, the producers of grey energy will have to pay 1 Daalder per unit of energy.
Let's start round 3 soon!

Round 3

The CST EYE News

Energy is more expensive every day!

Energy prices for households have risen significantly in recent years. As a result, residents are looking for ways to save energy to keep their energy bills affordable. The LEC has set up an energy desk to make it easy for residents and installers to contact each other. In addition, the LEC is launching a door-to-door sensitisation campaign to engage residents. This increases the demand for energy conservation among residents.

This enthusiasm around energy conservation allows installers **to install this round of energy savings without partnering with another party and without paying hearts.**

Round 3: Prepare the electrical grid

The grid operator is at it again: what do you want to do this round?

- Building connections
- Or building buffer capacity to accommodate peak and off-peak loads.

We do another quick tour of the other players: what do you expect to build in this round? [Start the timer at 5 minutes]

[Let each party speak briefly, and ask the grid operator to decide on what to construct]

Round 3: Negotiation

Now you all get to work. You have 10 minutes to decide which energy units to invest in. Your time starts NOW!

[set timer to 10 minutes]

[reminder after 5 minutes]

[announce last minute, count down last seconds]

[After 10 minutes]: Time is up! We are going to the payout phase!

[Optionally, the last energy cards may still be put down, but be strict: in the Real World, time is ticking too]

[ROUND 3: REFLECTION ADDITIONAL NEWS RELEASE]

[Read out only if in round 2 the intervention 'additional news item' applied]

We ended the last round with an additional news release that made it clear that renewable energy is needed quickly. An ultimatum of 60% renewable energy was set, so 6 energy units must be renewable this round.

Before we go to pay off, we'll see if you met this objective.
[Review whether Option1 or Option 2 applies and read the corresponding text. Round down if necessary]

1. At least 60% of energy is renewable! The region is happy that its plan worked and it can avoid the fines. Residents are happy that the region's taxes will not go up.
2. Less than 60% of the energy is renewable. Naturally, residents are not happy about this. The region is frustrated that so much grey energy is still being generated. The bill to make the polluter pay is passed. The region's taxes go up as a result. From now on, producers of grey energy will pay 1 Daalder tax per unit of energy each round. [Take the tax.]

Round 3: Payout

Now to the payouts. I'll start with the fixed payouts:

Then the investments, let's see who invested.
[Go through all the parties one by one and see what energy they have invested in. Pay everyone out loud]

Round 3: FINES?

Have energy suppliers met the energy demand?
There must be 10 cards on the playing field each round to avoid a blackout.
[Failed? The power company, the renewable energy company and the cooperative will each be fined 2 Daalders. If they do not have Daalders, the fine may also be paid in hearts.

If they have no means of payment at all, they receive 2 loan cards from the bank. This must be paid off the next round].

Did the grid operator provide sufficient grid capacity?

Newly built solar farms cannot be built on a space without a sustainable connection.

[Are there generation units without a connection? Then a blackout occurs. The grid operator is fined 1 Daalder]

In addition, there cannot be more solar farms on the playing field than the number of units of buffer capacity. This buffer capacity is represented by a battery icon in the upper right corner.

[Count out loud the number of buffer units and the number of solar farms. More solar farms than buffer units? The peak and off-peak load cannot be absorbed by the grid. The grid operator is fined 1 Daalder. Add up both fines if necessary]

Round 3: Reflection

At the beginning of this round, there was a news report about efforts towards improving energy efficiency for households and consequently reducing their energy prices.

How did this go? [See if option 1 or option 2 applies and read the corresponding text]

1. At least two units of energy were saved this round. As a result, residents' energy bills have remained affordable. Residents are relieved. Every energy conservation investor earns one more heart. [Pay the hearts; turn the round card white side up].
2. Unfortunately, the energy conservation question was not completed this round. The installers did not have their customer records in order and did not follow up on incoming requests. Residents are angry about their high energy bills and are switching back to traditional biomass. The energy company loses 6 Daalder of its capital. Take the fine [Turn the round card dark side up].

Reflection Follow-up

In this round, we talk to the cooperative

- Are we on track to meet our goals?
- What should be different for the next round?

ROUND 4

The CST EYE News

Solar farms are significantly cheaper!

A technological breakthrough in solar panel production has made them much cheaper. Residents expect the region to achieve its climate goals in this way easily. As of now, a solar microgrid costs 1 Daalder and one heart.

Round 4: Prepare the electrical grid

The grid operator is at it again: what do you want to do this round?

- Building connections
- Or building buffer capacity to accommodate peak and off-peak loads.

We do another quick tour of the other players: what do you expect to build in this round? [Start the timer at 5 minutes]

[Let each party speak briefly and ask the grid operator to decide on what to construct]

Round 4: Negotiation

Now, you all get to work. You have 10 minutes to decide which energy units to invest in. Your time starts NOW!

[set timer to 10 minutes]

[reminder after 5 minutes]

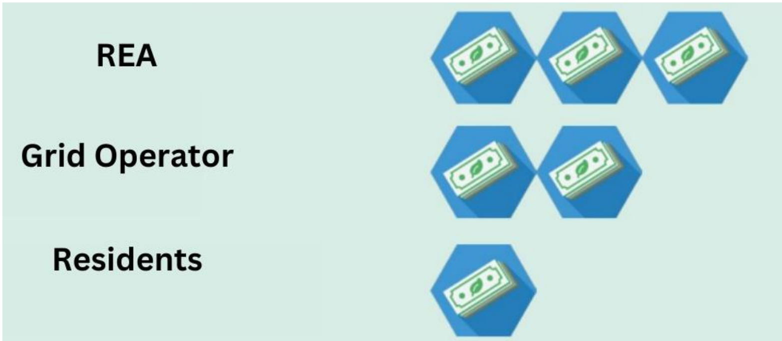
[announce last minute, count down last seconds]

[After 10 minutes]: Time is up! We are going to the payout phase!

[Optionally, the last energy cards may still be put down, but be strict: in the Real World, time is ticking too]

Round 4: Payout

Now to the payouts. I'll start with the fixed payouts:



Then the investments, let's see who invested.

[Go through all the parties one by one and see what energy they have invested in. Pay everyone out loud]

Round 4: FINES?

Have energy suppliers met the energy demand?

There must be ten cards on the playing field each round to avoid a blackout.

[Failed? The power company, the renewable energy company and the cooperative will each be fined 2 Daalders. If they do not have Daalders, the fine may also be paid in hearts.

If they have no means of payment at all, they receive 2 loan cards from the bank. This must be paid off the next round].

Did the grid operator provide sufficient grid capacity?

Newly built solar farms cannot be built on a space without a sustainable connection.

[Are there generation units without a connection? Then a blackout occurs. The grid operator is fined 1 Daalder]

In addition, there cannot be more solar farms on the playing field than the number of units of buffer capacity. This buffer capacity is represented by a battery icon in the upper right corner.

[Count out loud the number of buffer units and the number of solar farms. More solar farms than buffer units? The peak and off-peak load cannot be absorbed by the grid. The grid operator is fined 1 Daalder. Add up both fines if necessary]

Round 4: Reflection

At the beginning of this round, there was a news report about a technological breakthrough in solar panel production and the consequent reduction in their price.

How did this go? [See if option 1 or option 2 applies and read the corresponding text]

1. Congratulations!!! We managed to supply all 10 energy units. The CST has achieved its goals, and the inhabitants are proud of all efforts made. The territory has set an example for the rest of Uganda. This exemplary role generates positive publicity and attracts new businesses. The LEC receives 3 Daalders and 3 hearts. [Pay the bonus; turn the round card white side up]
2. Unfortunately, we did not succeed. The CST is energy supply is not sustainable. Residents are losing faith in the energy agreement. Each party must hand in one heart or, if they do not have it, 2 money units. [Take the fine: Turn the round card dark side up].

FINAL REFERENCE

Welcome to "The Central Service Territory At the Table." In this broadcast, we talk with all the parties who participated in implementing the CST Sustainable Energy Agreement.

The agreement clearly describes what you wanted to achieve together, but what did you want to achieve individually, and did you achieve these goals?

[Let each party speak briefly about the objective on the role card.]

I am very curious about what you have learned from the past 16 years:

1. What insights did playing the game give you? [Give each player the floor]
2. To the cooperative: What was playing a local energy cooperative like? [Give the cooperative the floor]
3. To the other roles: In your role, what did you think of the cooperative? Did you want to cooperate with it? Or did you not? [Give each player the floor]
4. The cooperative has much to do with "hearts," which express community support and backing. Do you think those add enough value? Or is it mainly about Daalders? [Give the floor to those who wish to comment on this.]
5. What action will you take in the short term as a result of this game? [Give each player the floor]

Thanks for your participation!

B. Surveys and Questionnaires

B.1 Survey on Generation technologies and associated attributes

Questionnaire Instructions

The questionnaire consists of 5 questions.

For the first two questions kindly rank the options in order of importance, 1 being most important and 5/9 being least important.

For all the questions below, a text box is provided to include any additional comments or suggestions on other points that may not have been mentioned.

1. What aspects do you consider most important when choosing energy technologies?

	1	2	3	4	5
Sustainability	☐	☐	☐	☐	☐
Technology Maturity	☐	☐	☐	☐	☐
Reduction in energy prices	☐	☐	☐	☐	☐
Social acceptance	☐	☐	☐	☐	☐
Political support	☐	☐	☐	☐	☐
Other: Please specify in the field below					

2. Taking into account the above-mentioned aspects, which are the most favourable technologies for rural electrification to be explored in the next 10 years?

	1	2	3	4	5	6	7	8	9
Large Hydro	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mini-hydro	☐	☐	☐	☐	☐	☐	☐	☐	☐
Oil	☐	☐	☐	☐	☐	☐	☐	☐	☐
Nuclear	☐	☐	☐	☐	☐	☐	☐	☐	☐
Solar (Large-scale)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Solar (Off-grid)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Biomass	☐	☐	☐	☐	☐	☐	☐	☐	☐
Geothermal	☐	☐	☐	☐	☐	☐	☐	☐	☐
Peat	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other: Please specify in the field below									

3. Given your organisation’s role in the electricity sector, what are your main objectives and what are some of the challenges in meeting the stated objectives?
4. What are some of your organisation’s current and future strategies to achieve your objectives? (For example, investments, geographical expansion, focus on consumer segments, technology choices, or collaborations with other stakeholders etc.)
5. For small to medium-scale energy initiatives, what aspects present the most uncertainty for your operations, **(technological, economic, social or political uncertainties)** and would therefore be of interest to explore with the tool/game? Kindly elaborate on your choices.

B.2 After-game Survey

Dear Sir/Madam,

Thank you once again for your enthusiastic participation in the game. Following yesterday's activities, I request you to answer a few questions regarding your role within the game and the use of serious games in general. In case you need more information on any of the questions asked below, please do not hesitate to contact me.

Sincerely,

Mieke Lawino.

On the role of Electric Cooperatives

1. What insights did playing the game give you?
2. Regarding the role of energy cooperatives in the game, what additional roles do you believe cooperatives could play in the current rural electrification system?
3. In your opinion, was the game a good enough depiction of the real-life dynamics of Uganda's rural electrification system?

On the use of Serious Games

1. Have you previously used or interacted with serious games? If yes, in what form was this, E-learning, Collaborative tools, Digital simulation, or Physical simulation?
2. In what ways would your company or work department be open to incorporating serious games?
3. What barriers would prevent the use of serious games within the ministry or your company/department?
4. Could serious games be incorporated into the decision-making processes within your company/work department? Please explain why so/not.
5. After playing the game, what are your perceptions on the possible use of serious games within the Ugandan context?

C. Additional Technology Discussion

The previous analysis highlights the importance of looking beyond the technical feasibility of different electricity generation technologies and analysing the context-specific social and economic aspects and how they interrelate. The discussion has mainly been on the techno-economic and socio-technical arenas. The technical discussion involved the physical availability of resources and technology, the economic discussion has been on the implications of selected technologies regarding investment costs and end-user affordability, and the social dimension mainly includes ease of adoption or use of different technologies as well as sustainability and environmental impact.

The biggest advantage of solar mini-grids for rural electrification is their scalability to growing demand. Moreover, the reduced cost of production of solar panels will make them more affordable for poorer societies. It is important to ensure a holistic approach to developing these grids, to look at them as modular connections that can be expanded to benefit not only from economies of scale but even as a means to improve reliability with excesses or troughs in the production shared between grids. Another important consideration is the disposal plans for the solar panels especially is they are to be commissioned on a large scale. The Balance of the System components of these systems significantly hikes their costs, specifically storage. Needless to say, this is an important aspect that should be considered as they are rolled out, and alternatives such as hybrid power production systems should be considered to counter the problem.

Hydropower is already widely in use in the country and does not usually require additional storage or the use of fuel. It can, in fact, also be used as a means of storage for more intermittent sources of energy. The source should be exploited for areas where it is a viable option.

The grid currently supplies the majority of the electricity in the country. However, a number of issues related to the grid need to be assessed, and it is important that grid extension efforts are pushed in tandem with the off-grid options if the country is to realise universal access within its set timeframes. Beyond technical viability, a number of other institutional, social and political solutions; for example, subsidies, end-user sensitisation and empowerment of cooperatives; need to be explored to solve the problems associated with this option.

Diesel generators are a mature technology that has proven to expedite rural electrification efforts in the country. Additionally, the country's current efforts in the oil industry could further reduce the cost of fuel. However, to counter the negative impacts of burning fossil fuels to a certain degree, the technology should be used in combination with more intermittent renewable technologies like solar and even mini-hydro to improve the reliability of the power supply.

Even within Uganda, different regions of the country are endowed with varying resources that could affect strategies for their exploitation, highlighting the need for an ‘editable’ tool that brings together, and fosters debate on the different perspectives discussed. The next chapter is about the development of a serious game to bring all this together.