Received: 3 December 2021 | Revised: 30 March 2023 | Accepted: 5 June 2023

DOI: 10.1002/sys.21706

REGULAR ARTICLE

WILEY

Energy planning in sub-Saharan African telecom networks: Decision support using a soft systems methodology

Mbiika Ceriano | **Jörg Lalk** | **George Alex Thopil**

Department of Engineering and Technology Management, University of Pretoria, Pretoria, South Africa

Correspondence
George Alex Thopil, Department of Engineering and Technology Management, University of Pretoria, Private Bag X20, Hatfield, 0028 Pretoria, South Africa.
Email: george.alexthopil@up.ac.za

Funding information
'Training the next generation of scientists' provided by Carnegie cooperation of New York through the Regional Universities Forum for Capacity Building, Grant/Award Number: RU/2020/GTA/DRG/014

Abstract

This research paper narrates the application of the soft systems methodology (SSM) as a problem structuring tool, as well as the first step of a methodological approach that will provide decision support based on multi-criteria decision analysis in the planning of energy for telecom networks across sub-Saharan Africa. To ensure applicability of the methodology to a real-world issue, an international telecom tower company based in East Africa was selected as the case study. The SSM is utilized to characterize the decision problem context precisely, identify major stakeholder groups and their connections, and to discover each one's interests. This helps to achieve appropriate and holistic energy planning and management unlike the current trends which employ a reductionist approach. The outcome of the work leads to a model using SSM where stakeholder inputs can be captured, for the telecom company.

KEYWORDS
decision support, energy planning and management, multi-criteria decision analysis, problem structuring, soft systems methodology, sub-Saharan Africa, telecom networks

1 | INTRODUCTION

According to Beuth Verlag,[1] "Energy management includes planning and operation of energy production and energy consumption units. Objectives are resource conservation, climate protection and cost savings, while the users have permanent access to the energy they need. It is connected closely to environmental management, production management, logistics and other established business functions".

The planning and management of energy in telecom networks can be specified as the decision-making process which involves assessing, selecting, and evaluating energy technologies/infrastructures to adopt, and the energy efficiency strategies to promote in telecoms. It encompasses policies that impacts energy consumption practices. Appropriate energy management and planning is a vital step to achieve sustainable development, facilitating to equate future energy supply with the future energy demand.[2,3] The planning and management of a holistic telecom network system is a complex process. It comprises of various stakeholders, determined by various factors which include—physical environment (natural eco-system and collateral infrastructure), political and regulatory, operational and institutional (sociological and cultural), financial and economic, and technical/technology factors.[3–7] This process intrinsically comprises of a number of issues, several and conflicting assessment criteria (technical, economic, environmental, political, and social), multiple stakeholders, and their interests.

Conversely, telecom network energy planning and management across sub-Saharan Africa (SSA) has not been handled appropriately and holistically.[7,8] This has necessitated a need for a systems thinking approach like the soft systems methodology (SSM) to structure decision support. Companies believe that custom power supply specifications and strategies especially for hardly reachable off-grid areas such as, efficiency, sustainability, reliability, and cost-effectiveness can be best solved by utilizing advancements in technical solutions, for example, deployment of green energy technologies.[7,9] This renders the current trends and practices of managing energy in telecom networks across SSA more of a reductionist approach. This approach focuses on the end result without caring about the interests/benefits of other ecological, economical, and social groups. It does not cater for holistic benefits of all involved stakeholders.[10,11] Companies have focused on massive rollout of infrastructure but have neglected holistic planning, design, and implementation of these infrastructures. This would bring universal benefits to all stakeholders especially when the challenges that the planners face are complex, messy, ill-structured, and multi-dimensional.[4] Indirect benefits necessary to achieve sustainable development have been ignored. Telecom network planning and management has been largely left to engineers, who mainly focus on upgrading and improving the technology. Little research on the social, economic, and environmental impacts of telecom networks has led to inappropriate planning.

Integrated, appropriate, and holistic energy planning and management involves finding universal solutions to the problems of sustainable development. This framing of holistic and appropriate energy planning and management call for a systems science/approach perspective—thinking in terms of relationships, patterns, and contexts[12.]

Companies, organizations, economies, industries, societies, and ecosystems are all complex, ill-structured, and self-regulating systems. They exhibit the same behavioral patterns most especially during the management of messes (responding to dynamic situations).[13] Therefore, a systems thinking approach like SSM assists to adapt, manage, and visualize a wide range of alternatives at stake. It also aids in identifying root causes for problematical situations and see new opportunities. It helps to understand relationships between system elements and their emergent behavior (intended and unintended), and how the system adapts with the changing environment.

The telecom network energy management process can be seen as a political process. This is because it comprises of negotiations and trade-offs among major stakeholder groups having interests in the planning and management process. Therefore, decision issues emerging in the telecom network energy management domain are well suited to be handled by applying multi-criteria decision analysis (MCDA) methods and techniques.[3,14,15] The main purpose of MCDA is to enhance the quality of decision making by giving analytical basis for the collation of conflicting remedies, since a prominent option does not occur when various competing criteria are at stake. This is achieved by: showing trade-offs among criteria in order for regulators, planners, other stakeholders, and the general public to comprehend the pros and cons of options; enabling people to reflect up on, express and use analytical judgements, leading to a choice, sorting, and ranking of options/alternatives. Additionally, MCDA also possesses some necessary characteristics that render it a suitable tool for studying complex issues, for example, telecom network energy management processes. Firstly, it can handle mixed data sets, qualitative and quantitative, including opinions of experts. Also, it is highly formulated to support a synergetic planning and decision-making domain. This interdisciplinary and collaborative environment enables the participation and involvement of various stakeholders and experts.[3]

There exists a large amount of literature about the application of MCDA techniques in energy management.[3,16–19] However, no past endeavors of applying a SSM as a problem structuring technique in the management of energy for telecom networks has been done. Mingers and Rosenhead,[20] conducted a survey of papers and reported practical usage of problem structuring methods (PSMs) but for over fifty applications, only a single paper reports SSM usage in the energy sector. Neves et al.[18] applied SSM in the study of general energy efficiency initiatives. Coelho et al.[3] applied SSM to structure the urban energy planning dilemma. Coelho et al.[15] applied SSM in structuring an MCDA model for sustainable urban energy planning. Ebrahimi[21] used SSM for the analysis of sustainable energy initiatives. Finally, Antunes et al.[22] applied SSM in the assessment of policies and incentive actions to promote technological innovations in the electricity sector. We found that energy management in telecom networks is not well documented in literature. It has little information available pertaining how energy management in a telecom networks context evolves in practice.

We are in the process of formulating a novel framework for guiding decisions based on the combination of systems approaches and MCDA approaches. This will be applied to facilitate decision-making in telecom network energy management issues across SSA for sustainable development. For this reason, a problem structuring step is described in this paper for arranging the problem situation using a systems thinking approach. This sets a base for the success of MCDA models and the deployment of MCDA techniques and methods.

Specifically, this paper answers the following research question (RQ) and its sub-question (SQ):

RQ: How can the SSM be applied to problem structuring of current telecom network energy management challenges across SSA? This question intends to utilize SSM in characterizing the decision problem context precisely. This helps to achieve an appropriate and holistic energy planning and management unlike the current trends which employs a reductionist approach. An international telecom tower company based in East Africa is used as the case study.

SQ: How can SSM be utilized to identify major stakeholder groups and their connections, and to discover each one–s interest (positive or negative)? This research sub-question intends to assist in developing desirable and feasible changes within various stakeholder groups. This helps to avoid unintended emergent behaviors hence leading to universal benefits for all stakeholder groups.

In this paper, we report the application of SSM as a problem structuring tool, and as an initial phase included in a methodological approach currently in the formulation process. This approach intends to provide decision support based on MCDA that can be applied to enable decision making in the energy management issues comprising of various stakeholders and various evaluation aspects. In order to apply the methodology to a real-world problem, an East African based telecom tower company was chosen as the case study.

This paper follows the following structure: Section 2 describes the telecom network system and also gives a description on how it exists as a socio-technical system; Section 3 gives a brief overview of a PSM with a rationale for our choice of SSM; Section 4 narrates how SSM is applied to structure problems related to the management of energy in telecom networks across SSA using the East African based telecom tower company as the case study. This includes descriptions for: formulation of a rich picture, construction of root definition, formulating a conceptual model, and making comparisons. The paper ends with concluding remarks including future work, acknowledgements, conflict of interest statement, and finally references.

2 | THE TELECOM NETWORK SYSTEM

This section describes the sub-Saharan telecom network energy system (STNS). Within the sustainable development framework, the current trend for market deregulation, and the increasing need of sustainable electricity generation through renewable energy technology sources, meeting the surging energy demand in telecom networks is a very critical issue. This is also triggered by the legislation coming from the 2015 Paris Conference of Parties (COP) summit held in Paris requiring the decrease of Green House Gases (GHGs).[23] Since sustainable development is firmly connected to energy use patterns and energy technology management, governments and stakeholders worldwide are implementing and planning more sustainable strategies to energy use, production and management.[3] Governments have powerful reasons to encourage sustainable energy planning and management approaches.[24]

The current SSA telecom network energy approaches, whose nature is both traditional and sectoral (mostly focusing on energy efficiency, demand, and supply), and the crucial connections between energy and economic-social-ecological development are not tackled in a holistic manner. This cannot address the connection of energy to other ill-structured, wicked and complex issues. Therefore, a multidisciplinary and integrative approach is needed to steer telecom network energy management in a way that can resolve wider problems related to energy.[3] All the factors that may integrate the telecom network energy management process need to be considered in this integrative approach. The main possible factors are: physical environment (natural eco-system and collateral infrastructure), political and regulatory, operational and institutional (sociological and cultural), financial and economic, and technical/technology factors.[3,4,6,7]

The acknowledgment of the implications of such synergism in the mentioned factors is a vital condition for understanding of the telecom network complex problem. Hence, a telecom network should be viewed as a telecom network system in reality, where technology (for example, energy technology like the application of a suitable renewable energy technology) is just one element or subsystem of the overarching telecom network system.

2.1 | Telecom network system as a socio-technical system

Technological systems do not exist on their own but ultimately for society,[3] hence, Warfield[25] defines "socio-technical" systems as a combination of technological systems and people. It may be concluded that the sufficient output of such a socio-technical system should mainly be underpinned by the synergistic interaction between technological and social aspects.

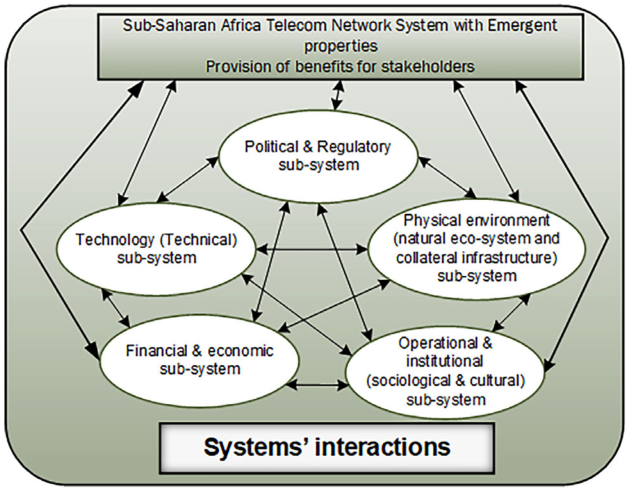


FIGURE 1 STNS showing the relationships between the subsystems and the emergent properties of the system.

Basing on system descriptions by Ackoff,[26] Andrew and Petkov,[4] Lane and Jackson,[27] Midgley,[28,29] SEBoK,[30] Von Bertalanffy,[31] and considering the energy management conundrum surrounding telecom networks across SSA,[7] it can be proposed that a particular STNS could be conceived as shown in Figure 1 below.

Although Figure 1 indicates boundary lines around both the entire system and subsystem, this is not absolute—see Klir,[32] for a clear explanation concerning constructivist view of systems. The STNS evolves based on the synergistic relationships amongst the sub-systems. The conceived system does not reflect all the possible subsystems.

The interplay, tensions, and interactions between different conflicting factors/sub-systems expressed in Figure 1 lead to the realization of this STNS. This concept also clearly portrays how the STNS depends on a number of mutually dependent subsystems leading to a system of systems.[33] Worth noting, is that, the energy technology subsystem/factor is just a subsystem inside the STNS, though a vital one. Telecommunications practitioners have commonly regarded this technology subsystem as the whole telecom network system, and hence, they have concentrated on it with the false expectation that it can single-handedly stimulate sustainable development in a particular area. The sustainability of a vibrant telecom network system cannot be achieved without a holistic consideration of other external factors during technology design and implementation. The emergent properties of a telecom network system in a particular area determine what needs to be considered while making decisions pertaining energy management approaches.[4]

The analysis of the current trends and practices in energy management of telecom networks across SSA portrays a reductionism approach to solve energy issues. It is, however, suggested that best practice should consider all other subsystems/factors shown in Figure 1 above in the planning, design, and implementation of telecom network energy management technologies/approaches.[4,34] Furthermore, Figure 1 shows that the emergent properties of the STNS are not solely dependent on the technology subsystem, but, they arise from the synergistic interactions amongst other different subsystems such as the physical environment (natural eco-system and collateral infrastructure), political and regulatory, operational and institutional (sociological and cultural), financial and economic subsystems.

Based on the existing research works[7,34–36] and stakeholder engagements, a critical analysis of the current practice indicates that companies only focus on technology in finding energy management solutions without any imperative to think in terms of the technology being an intervention into a society. Using a systems approach and a proper analysis of Figure 1, one can propose that the current practices are not comprehensive enough for a healthy STNS to develop.

In brief, emergent properties can be understood as "benefits of all stakeholders" of the system.[4,37] This means that, as long as conducive interactions within the subsystems exist, telecom companies, including any other investors and government companies can have all their expectations met in a particular area. Planners of technology infrastructures must take due cognizance of this while striving to provide energy access with the expectation of community development.

To comprehend the "systemic approach" concept to the concerned problem for universal stakeholder benefit, it is critical to dig deeper into the behavior and features of the STNS so as to understand the extent and nature of system complexity.

The system representation in Figure 1 is meant to represent a real system for the purpose of obtaining a clear comprehension of the issue at hand, and also to account for a systemic approach. Even though Figure 1 is a conceptual representation, two clear components of the STNS are people and technology, collectively also known as a socio-technical system. The next section discusses the possible PSMs for telecom network energy management dilemma.

3 | PROBLEM STRUCTURING METHODS

PSMs are the type of decision support techniques formulated to aid management teams to concur on the format and bounds of the problem situation under control, and to attain shared courses of action.[38–40] Hence, PSMs can aid stakeholder teams to gain a clear comprehension of a problematic situation specified by high complexity levels, conflict and uncertainty. Rosenhead[41] asserts that the problem scenarios requiring PSMs's analytical assistance are specified by *"multiple actors, multiple perspectives, incommensurable and/or conflicting interests, important intangibles and key uncertainties."*

Even though taking different shapes, PSMs have common specific characteristics and each PSM gives support for problem situations by representing the situation (i.e., a model or models) that can help participants to comprehend their problem situation, reach a consensus pertaining a possible practical common problem or inherent issue, and decide commitments that can at least partially resolve it.[3]

The most notable PSMs include: Strategic Choice Approach (SCA), SSM, Strategic Options Development and Analysis (SODA), Drama Theory, and Robustness Analysis.[40] Two main characteristics which are central to the SSM compared to other approaches are—structuring and facilitation. Facilitation focuses on availing a platform where participants/stakeholders are well guided and discussions or debates are sufficiently channeled. Structuring involves the process of organizing the problem situation in a format which stakeholders/participants can comprehend, and therefore eventually engage in the decision making and planning procedures. These methods are characterized as non-mathematical approaches, applying system-oriented techniques, ideas, concepts and processes, and stressing dialogue and involvement with the clients.

3.1 | Rationale for choosing SSM

Out of the numerous PSMs that could be applied, as recognized by a number of researchers as the initial step of a MCDA application[,42,43] SSM (Figure 2) was selected. The core reasons for SSM's selection include its flexibility in expressing the problem situation, the ability to stimulate learning, exploitation, interpretation, and appreciation of the associated problematical situation amongst diverse stakeholder groups. The choice was also premised on the author's familiarity with systems engineering knowledge, principles, and practices.

SSM is a fully fledged, meticulous, and prominent methodology that has been applied through a number of ways, fields and countries, and which bases on strong principles.[3] SSM is also utilized to characterize the decision problem context precisely pointing out the major stakeholders with their relationships, and discovering each one's interests.[44,45]

Checkland,[46] introduced SSM as an analytical and action-oriented procedure for refining ill-structured problem situations where issues to be covered are unclearly understood and not well explained. SSM is an orderly way of handling perceived problem (social) situations. It is action-based and focuses on learning about problem situations to improve courses of action, and not on the solution design. SSM is suitable for resolving conflicts emerging from diverse worldviews, and therefore conflicting objectives, of the different stakeholders.[3] Bearing in mind to formulate a methodology for evaluating different alternatives in the novel framework of energy management problems, the SSM's proficiency to express all the issues of different nature that need to be included into MCDA models have been acknowledged as a SSM benefit for bridging the structuring and the alternative assessment/evaluation phases[18] explains a merged SSM-MCDA method to give decision support in the assessment of initiatives for enhancing energy efficiency. SSM has been acknowledged as a crucial tool in problem situations emerging in the energy systems because it contributes to: clarifying complex ill-structured issues; probing the system and discerning the fact that there exist other system boundary definitions; stimulating comparisons.[47]

4 | APPLYING SSM TO THE MANAGEMENT OF ENERGY IN TELECOM NETWORKS

The application of SSM to the management of energy in telecom networks across SSA followed a typical 7-stage analytical process as

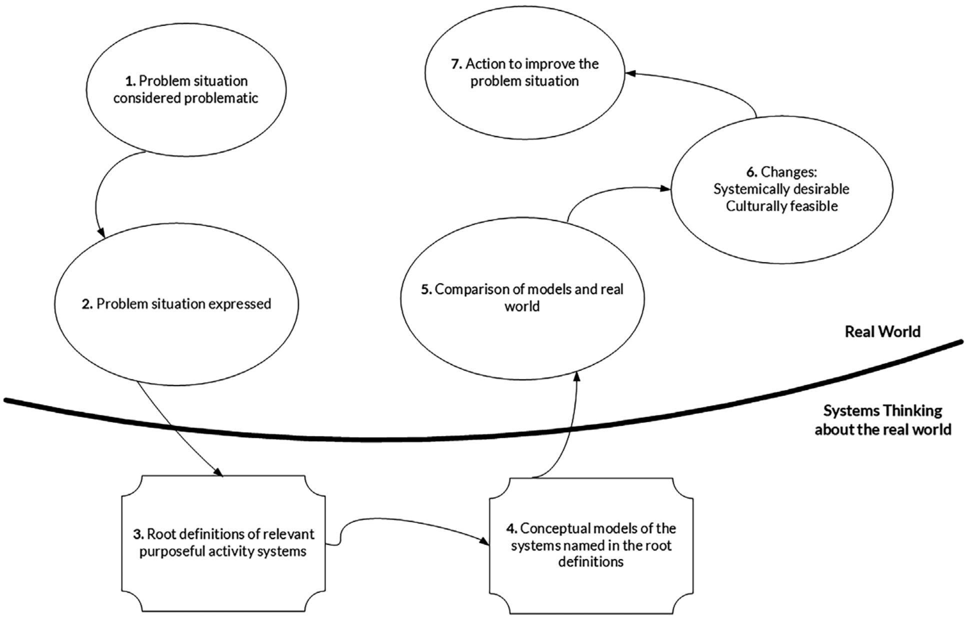


FIGURE 2 Seven steps of SSM.[48,49]

explained in ref. 46 and presented in ref. 22. The model consists of five stages lying in the real-world thinking, with two stages for comprehending and discovering more about the problem at hand and the remaining three stages for bringing recommendations of change and taking courses of action for improving the problematic situation. There exist two stages associated with systems thinking, where conceptual models and root definitions are formulated.[50]

With regard to procedures of making policy decisions, this often means early recognition of related stakeholder groups (see Figure 3) and the incorporation of their interests and preferences in the procedures. Decision makers possess 3 core intentions: firstly, to create knowledge with regard to the problem context, secondly, to use it in the service of a problem description, and eventually, to make a comprehensive plan for action. This tripartite arrangement works as a specific helpful framework for comprehending the dominant usage of SSM core tools.[3,51]

The "finding out" tasks are performed in the real world where different stakeholder views pertaining immediate contextual matters are explored. The identification of different appropriate process stakeholders was done by conducting interviews with experts and an expansive scope of stakeholders from the selected telecom tower company. The conducted interviews targeted specific questions for various stakeholder groups, and rotated around these issues: the role of stakeholders in the management of energy for telecom networks and their insight on crucial aspects, issues, challenges, problems, gaps, and opportunities pertaining energy systems. The deliberations arranged around these issues targeted a better understanding on how telecom network energy management process evolves in practice.

The "finding out" process of a problematical issue involves four ways that have turned into a standard of applying SSM: formulating rich pictures, and realizing three types of inquiry, that is, Analysis One, Two, and Three.[52] These mentioned analyses give, apart from the rich picture, additional frameworks that aid in comprehending the problematical situation sufficiently.[11,44,52]

Analysis One examines the intervention into the problem situation itself as being problematic. Three roles are examined here: the client—that is, one that caused the study, the would-be problem solver and the owner of the problem.[49,52] In this study, the participant also tries to discover who all the "stakeholders" are, that is, groups who are interested in, and are possibly impacted by the situation. This data serves as the initial step for information sources with respect to the situation. *Analysis Two* is associated with the constantly varying interaction between values, behavioral norms and social roles.[49,52] *Analysis Three* concerns itself with issues like politics and power and how its expressed, distributed, demonstrated, spread, used or allocated.[49,52] This encompasses an inquiry into the formal power structures including the informal leadership which is given and accepted. The data about this analysis aids the facilitator during the next stages of the SSM procedure. Basically, the three analyses serve as an instrument of analysis: pick someone involved, point out the type and extent of their power and express their contextual affiliation.[3,51,52]

4.1 | Rich picture formulation for energy management in telecom networks

A rich picture is a graphic illustration that represents all the stakeholders, their inter-connections and concerns. It is aimed to be a wide, highly-grained outlook of the problem situation. Rich pictures originate from group work by unwinding and integrating understandings.[53] Constructing a rich picture necessitates the facilitator to work hand in hand with groups of stakeholders so that the illustration incorporates the situation and associated concerns from the stakeholders' perspective. Hobbs and Horn[54] points out that the timely participation of the public

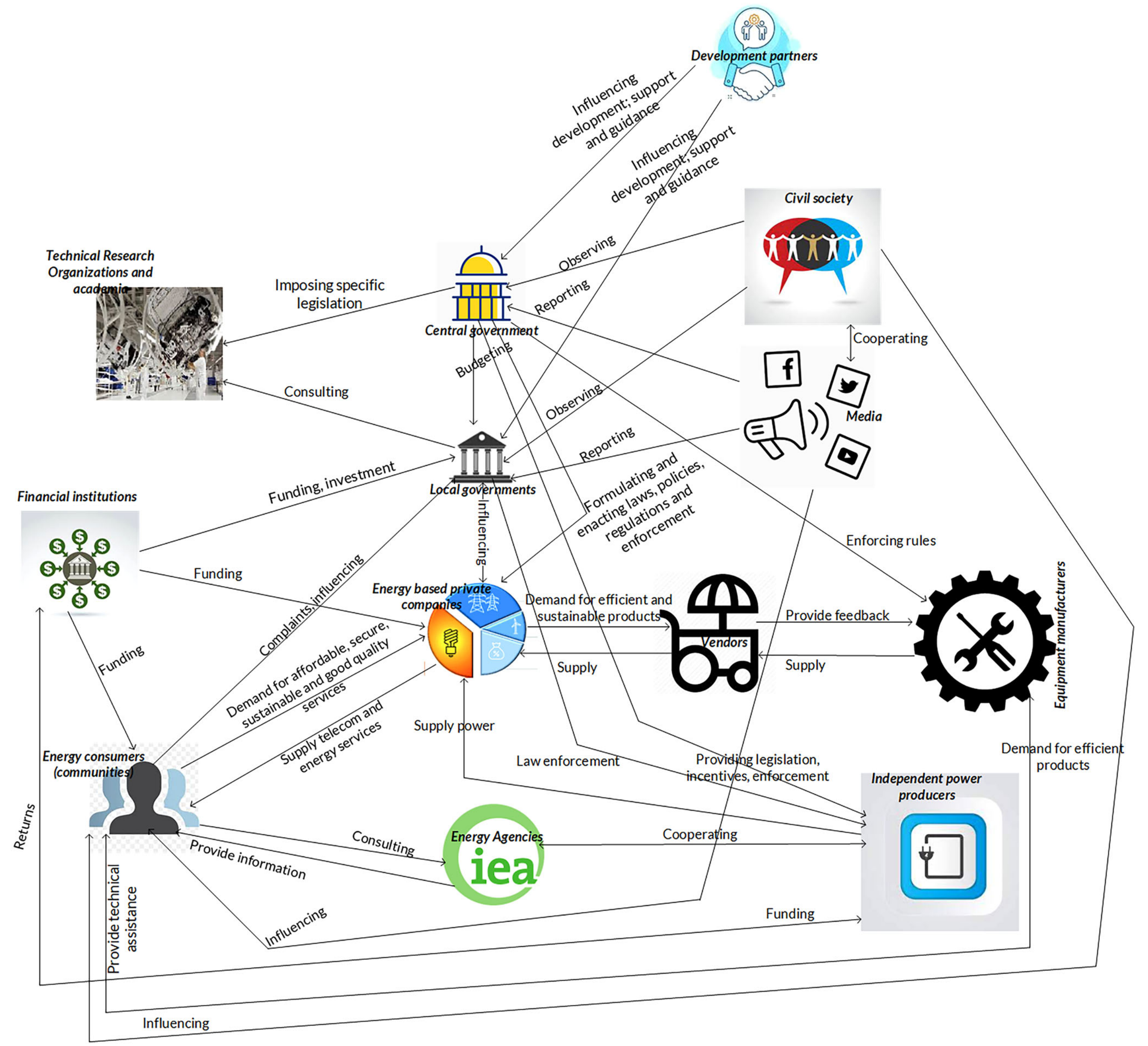


FIGURE 3 Rich picture of SSA telecom network energy management.

in energy decisions is crucial to: ensure that local community values are incorporated in decisions; secure information related to impacts that may otherwise be neglected; inform the local community; and also improve fair play and clarity of the energy management process.

The accomplishment of these purposes assists in winning support and confidence from the public both for the decision process and its end result. Based on the gathered information via interviews, the following stakeholders bearing diverse interests and preferences appeared pertinent: central government authorities, local governments, development partners, civil society, energy consumers/citizens, technical research organizations and academia, equipment manufacturers, vendors, energy agencies, and the private sector which includes financial institutions, independent power producers, energy based private companies such as telecom tower companies, energy service companies, mobile network operators, fuel suppliers, vendors, and other contractors. The derived rich picture is illustrated in Figure 3. This is the typical illustration of the main stakeholders (including other components) and the connections between them. The illustration tries to capture the norms, values, power relationships, and attitudes in the situation under appraisal. The main stakeholders and their roles are discussed below.

Central government authorities—formulate and enact legislation, policies and regulations for the energy sector and ensuring their enforcement; promote efficient and sustainable use of energy; promote innovation and creative ideas in the energy sector; create favorable conditions for energy business; can accept or reject attempts for financing a special project. *Local governments*—responsible for government's decentralization initiatives; manage and implement policies on the use of energy resources; ensure that local resources and infrastructure are used properly and sustainably; develop by-laws for guiding development and utilization of local energy resources and systems sustainably; close supervisions and watch on substantial government projects for the good of the local community and the entire nation; can stop any project; ensure markets for novel technologies; give incentives to local energy producers; demand more responsibility in the energy planning and management processes. *Development partners*—assist government via technical support and guidance; budgetary support and financing for developing, implementing, monitoring, supervising and evaluating the policy implementation; they influence government's directions on energy policies, and statutory rules for funding eligibility through sources or programs. *Civil society*—this includes elements like non-governmental organizations and other civil sector arrangements like media. They create awareness; disseminate information; mediate in communicating needs, expectations, capabilities, and responsibility between the public, government and the private sector; ensure that social, economic and political obligations are met; analyze projects' impacts on environment and social welfare; they exert an increasing pressure to influence laws; media is charged for publicizing educative information related to the energy sector for the public and other stakeholders. *Private sector*—they play a vital role on investing capital and other resources into the energy sector; produce and sell energy technologies and products, consume energy hence generating government revenue; some serve as energy producers through co-generation; mitigating any adverse environmental impacts of energy exploration, production, use and disposal; influence how quickly you can implement projects; supply energy related services; energy companies target low costs, high returns, supply reliability and interoperability with the current infrastructure; aim at energy infrastructure enhancement; demand for energy supply system involvement; aim at a long life and smooth management of production systems; vendors supply both energy technology and services. *Energy consumers/citizens*—monitor and react to environmental effects of energy projects and programs; hold responsible parties to account; demand for participation and contribution to projects; minimize possible conflicts and rejection of energy technologies and projects; ensure infrastructures are safe and not vandalized to obtain their expected operational lifetime; concerned with energy costs; have necessary powers to effect decisions of all the stakeholder groups. *Technical research organizations and academia*—developing energy solutions that address country's specific energy needs and sustainably exploit the usage of available resources; keep abreast of research developments regionally and internationally; adopt better practices customized for the local scenarios while utilizing local resources; training and skilling of energy workforce; act as information sources and decision makers' consultants; are compelled to observe national and local rules and norms. *Equipment manufacturers*—give technical guidelines and assistance; can often support the realization of some consumption reduction measures; target to boost sales; can be compelled to bring efficiency on the market through standard and compulsory labelling; support training on equipment usage. *Energy agencies*—they provide information, demand for inclusion in the management process; promote initiatives and supervise the program execution processes; support and cooperate with government to achieve its energy related programs.

The next sequence of interviews was conducted to seek for stakeholders' comments and opinions pertaining issues that may have been skipped, undervalued, misunderstood or overvalued. Their feedback was helpful in rich picture improvement. It also helped in the comprehension of the cultural and social aspects of the problem situation, which forms the subject of Analyses One, Two, and Three.[52] It is also worth noting that the "finding out" task is never completed, it continues throughout the study and should never been seen as an initial activity which can be finished before the commencement of the modelling process.[55,56]

The stakeholders chosen to participate in this research were key individual members that were chosen based on their extensive knowledge, skill and involvement in the telecoms and energy sectors. However, elements of some subjective influence on the results cannot be fully excluded.

4.2 | Building the root definition

At this stage, the practitioner goes into the "systems thinking world" where a root definition is built based on systems that are relevant to the identified problematical situations. A root definition is mainly a sentence which delineates, in an abstract manner, the system's basic nature when analyzed from a specific angle.

As a guide to root definition building, Checkland[46] gives the CATWOE components indicating that an absolute root definition should single out the Customers (C), the Actors (A), the Transformation (T), Weltanschauung ("world view") (W), the Owners (O) and the Environment (E).

The CATWOE mnemonic emerges into the following definitions:

Customers—are the system's beneficiaries or victims who benefit or are impacted by the system's output. The victims: energy/telecom based private companies that decrease sales; equipment manufacturers whose products/services are replaced. The beneficiaries: the consumers who gain with low energy prices, reliable and sustainable energy supply, and possess freedom of choice; equipment manufacturers who gain from the increased transactions for efficient equipment/technologies; the communities/citizens/society as it is concerned with sustainable development and national energy dependence.

Actors—are the ones with the technical expertise. Technical planning teams consisting of telecom and power network planners, producers, developers, specialists and energy based private company heads.

Transformation—These are changes that take place inside or because of the system. Current reductionist approach employed in telecom network energy management → a holistic management of energy in telecom networks across SSA that defines goals, strategies, techniques, policies and procedures so as to match future demand and supply in a sustainable manner.

Weltanschauung—A holistic management of energy in telecom networks that targets to enhance decision making by supporting actors involved in or impacted by energy management of telecoms across

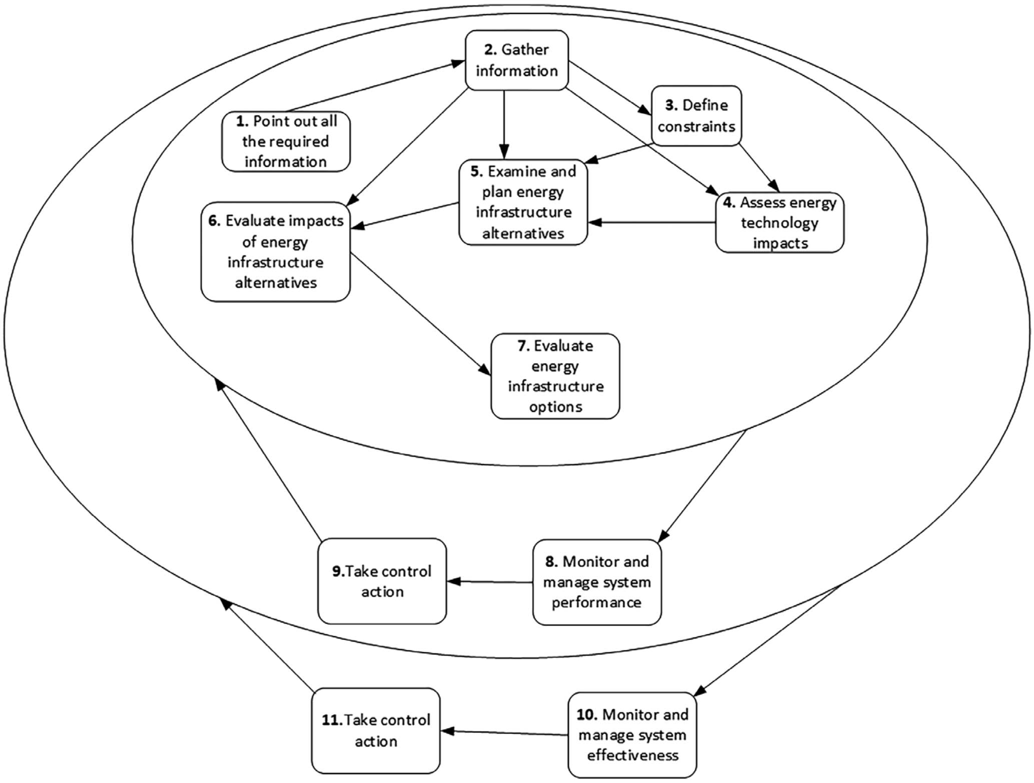


FIGURE 4 System's conceptual model.

SSA in choosing a suitable mix of energy technologies for sustainable development.

Owner—Telecom/Energy/Tower companies across SSA, having a wider view on the problem, is considered a sole decision maker. Telecom companies across SSA are the authority of reference and possess the primary responsibility of the system, and the utmost powers to give rise to a system's existence or termination.

Environment—Hardship for influencing decisions in a complex environment and the ability to challenge current energy management trends; economic, ecological, social, political and technological constraints; international concessions and direction.

The above delineated CATWOE results into the following root definition: "A system to provide decision support to the telecom companies across SSA, in the framework of sustainable telecom network energy management, to be operated by technical planning teams, which involves aspects for energy demand and the selection of options that impact telecom network energy systems (in the perspective of general energy management) to be assessed as per various axes of appraisal"

4.3 | Conceptual model

After completing the formulation of root definition, the following step concentrates on analyzing the activities necessary for achieving the transformation. The conceptual model takes place in the "system thinking" world and it helps in comprehending the problem situation. According to ref. 46 and refs. 57, 58, conceptual modelling is premised on the CATWOE components and root definitions; it is carried out by the usage of verbs to delineate tasks and by constructing those tasks in terms of how they logically depend on each other. A root definition represents what the system is all about, as compared to a conceptual model which represents what the system must perform so as to be the system named in the root definition.[52]

Figure 4 below was built based on the root definition. The illustration for the modelling process comprises of seven core tasks, and also covers activities for performance monitoring and control in the transformation process. Tasks 1 and 2 are concerned with the recognition and collection of all required data for example: rules of legislation, available energy infrastructures, local accessibility of renewable energy technology sources, categories of energy conversion technologies, available energy carrier categories, chances for improving energy efficiency, etc. These tasks may require energy demand models necessary for acquiring future volumes and patterns of energy demanded, considering economic development and growth rates. Task 3 is required to delineate all the constraints associated to the telecom network energy systems: ecological, economic, political, and technical constraints including constraints associated with capacity and resource availability.

Task 3 defines constraints that may be incidents related to choice of technology, whose effects on energy demand and supply cannot be ignored. The assessment of technology impacts, that is, ones associated with capital expenditure and operational expenses, reliability and performance, acceptance, confidence and applicability is done in task 4. The effect on the environment and on the energy systems must also be assessed. Task 5 requires information gathered in tasks 2, 3, and 4 for examining supply alternatives matching future energy demand in terms of forms and amounts of energy and plan the energy infrastructure alternatives. It necessitates the study of the existing energy infrastructures and the evaluation of future energy supply alternatives, utilizing available technologies, and resources.

The evaluation of the effects of energy infrastructure alternatives is done in task 6 and necessitates that the preferences and interests of the relevant stakeholders, brought out from the interviews and risen out from the structuring phase and root definitions are moved into criteria. The evaluation must accommodate all stakeholders' issues and aspects, encompassing aspects expressed in various units and even measured in qualitative forms.

The appraisal of alternatives done in task 7 is one of the core objectives of this system and it calls the need for a multi-criteria approach that enables the possibility of including the preferences of the decision makers into the decision support process. Analytical Hierarchy Process (AHP)[59,60] appears to be a satisfactory algorithmic choice because of its capability for organizing and analyzing complex decisions using maths and psychology in addition to the usage of various scales (qualitative and quantitative) for distinct criteria.

Checkland and Scholes[49] states that monitoring and control comprise of three tasks: the definition of Efficiency, Effectiveness and Efficacy (so-called three Es); the monitoring of tasks commensurate with the metrics defined for the three Es; and making action-oriented reactions while utilizing the mentioned metrics. In the telecom network context, the usage of indicators enables the monitoring of rates of return, the evaluation of efficiency (will it function with minimal resources—expressed in money and time) and the control of system efficacy (will it work at all—expressed in terms of alternatives offered, acquired and supplied at suitable quality), though the system still requires to be effective. The effectiveness in the telecom network energy management may be pledged through the development of long-term sustainable approaches.

4.4 | Comparison

At this stage, systems thinking gives a layout for discussions on the changes targeting to enhance system's performance based on the ideas expressed in the root definition.[10] According to Checkland and Poulter[44] layout for the debate is given by utilizing models as a source for questions with respect to the problem situation.

Four methods for carrying out the comparison as reported by Checkland[49,55] are: "informal discussion; formal questioning; scenario writing based on operating the models; and trying to model the real world in the same structure as the conceptual models". Formal questioning has been applied more frequently compared to other techniques.[49]

In this research, the comparison was done in an informal manner but also accompanied by formal questioning of experts from the selected telecom tower company. Part of the interviews already conducted provided contributions for comparisons between models and the real world. In the comparison phase, more interviews were held while utilizing a formal questioning approach.

Specific matters from the comparison phase that need to be considered are:

Enhance energy supply/demand analysis and forecasts. It is believed that this can assist in analyzing historic and current data necessary for energy planning, production and operation. Energy supply/demand analysis is a vital element of integrated energy planning and management. This is an issue that is overlooked by the current approaches.

Carryout and maintain records of information on local sustainable, renewable sources and new technologies. This is because they are vital in the provision of sustainable energy services premised on the use of routinely available indigenous resources. Their economic-social-ecological benefits also point in the opposite direction compared to the fossil fuels which are currently used to power off-grid sites.

Avail and maintain records that have statistical information related to the energy sector including ones related to ecological impacts. This data management plan helps in integrated energy planning and forecasts. Based on stakeholder engagements, this is non-existent in the current approaches.

Ease of communication among stakeholders and enhance people's involvement in identifying opportunities to change. The current reductionist approach does not use this practice. It only focuses on securing energy solutions hence blocking opportunities for universal stakeholder benefits.

Carryout a preparatory screening of the constraints in the core topics. This helps in exploring issues for improvement. It also definitely aids to establish potential or new progress. The screening of constraints assists in the framing of goals which must be considered while carrying out universal energy planning.

Maintain a monitoring process to assess constraints. This is good for integrated energy planning and management and lacks in the current approaches. It can assist in computations for actual energy usage, energy needs estimation, tracking of energy metrics and highlighting other issues that may deem necessary.

Select measures and units of all the indicators, establish outcomes on the indicators and also conduct impact evaluation using quantitative modelling and qualitative analysis.

Utilize a decision support system hinged on a multi-criteria approach dedicated to rate alternatives in predefined ordered classes and adopt a holistic energy planning and process. Based on stakeholder engagements, the current approach does not apply such systems approaches. The focus is to obtain a solution to the energy challenges.

Based on the outcomes acquired through the discussions carried out through this phase, changes have been recognized that could ameliorate the problem situation in telecom tower companies. The evaluation of these changes is being conducted through more consultations with the major stakeholder groups.

5 | CONCLUSION AND FUTURE WORK

This research paper presents an application of a procedure based on SSM for structuring problems related to the management of energy in the SSA telecom networks context, as an initial step for the formulation of MCDA tools to assess different sets of intended actions. In this paper, SSM was utilized to characterize the decision problem context more precisely so as to achieve an appropriate and holistic energy planning and management unlike current trends which employ a reductionist approach. The problem situation was discovered and expressed precisely mainly by using the initial stages of SSM, that is, the "finding out" process which involves Analysis One, Two, and Three plus the formulation of rich picture, hence answering the RQ. To answer the SQ, SSM was utilized to identify major stakeholder groups and their connections from interviews, structuring phase, and root definitions. Through conceptual modeling, activities that should be done by actors to achieve a desired transformation for the appropriate and holistic energy management of telecom networks across SSA were analyzed and presented. This intends to assist in developing desirable and feasible changes within telecom tower companies and various stakeholder groups so as to avoid unintended emergent behaviors hence universal benefits for all stakeholder groups.

The concept in this paper will, as the next step, be complemented and improved through more research, and it will form one of the steps in the formulation of a novel framework for managing energy in telecom networks across SSA. The use of the MCDA approach[17,61] will follow to assist in the formulation of the framework for sustainable energy management (planning, selection, procurement, adoption, etc.) in telecom networks across SSA. A range of varying criteria with trade-offs will be considered while selecting and adopting relevant sustainable energy choices for telecom networks across SSA. A decision-making matrix premised on both quantitative and qualitative data will be utilized to score the criteria. The research's objective is to contribute towards—from a SSA context—key impediments to the adoption of sustainable and better energy management approaches, aid in investment decisions, and eventually contribute towards a sustainable energy infrastructure. This phase of problem structuring brings out sets of preferences, concerns and interests from the relevant stakeholder groups with their power relations. This data are then utilized to plan the decision support stage, for example, concerning the formulation of criteria trees suitable for assessing interventions in holistic telecom network energy management.

ACKNOWLEDGMENTS

We dedicate this paper in memory of our primary author who passed away during the review process. Support for this research was made possible through a capacity building competitive grant 'Training the next generation of scientists' provided by Carnegie cooperation of New York through the Regional Universities Forum for Capacity Building (RUFORUM). Grant/Award Number: RU/2020/GTA/DRG/014. This work was also based on the research supported in part by Kyambogo University staff development funding, and the University of Pretoria's funded internal grants.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest in this research paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Mbiika Ceriano https://orcid.org/0000-0003-0309-3268
George Alex Thopil https://orcid.org/0000-0002-4196-2455

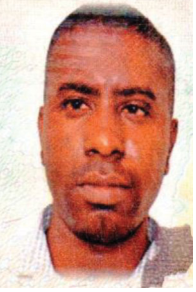
REFERENCES

1. Beuth Verlag. *What Is Energy Management*; 2007.
2. van Beeck N. *A new decision support method for local energy planning in developing countries*. Tilbg Univ Tilburg; 2003.
3. Coelho D, Antunes CH, Martins AG. Using SSM for structuring decision support in urban energy planning. *Technol Econ Dev Econ*. 2010;16(4):641-653.
4. Andrew TN, Petkov D. The need for a systems thinking approach to the planning of rural telecommunications infrastructure. *Telecomm Policy*. 2003;27(1-2):75-93. doi:10.1016/S0308-5961(02)00095-2
5. Andrew TN. *A SYSTEMS THINKING APPROACH TO THE PLANNING OF By Theophilus Nethiekreethum Andrew Submitted in Fulfilment of the Academic Requirements for the Degree of Doctor of Philosophy (Information Technology) in the School of Mathematics, Statistics and Informa*; 2001.
6. Foxon TJ. A coevolutionary framework for analysing a transition to a sustainable low carbon economy. *Ecol. Econ*. 2011;70(12):2258-2267. doi:10.1016/j.ecolecon.2011.07.014
7. IFC GSMA Powering Telecoms : East Africa Market Analysis. 2014:1-28.
8. TowerXchange. ESCOs emerging as critical new buyers of telecom energy equipment. 2020. https://www.towerxchange.com/meetup/esco-roundtable/esco-research/
9. Alsharif MH, Nordin R, Ismail M. Energy optimisation of hybrid off-grid system for remote telecommunication base station deployment in Malaysia. *Eurasip J Wirel Commun Netw*. 2015;2015(1):1-15. doi:10.1186/s13638-015-0284-7
10. Checkland PB. Soft systems methodology. *Hum Syst Manag*. 1989;8:273-289. doi:10.3233/HSM-1989-8405
11. Checkland P, Poulter J. Systems Approaches to Managing Change: A Practical Guide; 2010.
12. Capra F, Luisi PL. *The Systems View of Life: A Unifying Vision*. Cambridge University Press; 2014.
13. Visser W. Integrated innovation: applying systems thinking to sustainable innovation and transformation. *Sustain*. 2020;12(13):5247. doi:10.3390/su12135247
14. Mavrotas G, Diakoulaki D, Caloghirou Y. Project prioritization under policy restrictions. A combination of MCDA with 0–1 programming. *Eur J Oper Res*. 2006;171(1):296-308.
15. Coelho D, Antunes CH, Martins AG, Grasserbauer M, Sakalauskas L, Zavadskas EK, Using SSM for structuring an MCDA model for sustainable urban energy planning. Proc EURO Mini-Conference–5th Int

Vilnius Conf''Knowledge-Based Technol OR Methodol Strateg Decis Sustain Dev Vilnius, Lith Vilnius Tech. 2009;(July 2014):102-107.
16. Løken. Use of multicriteria decision analysis methods for energy planning problems. *Renew Sustain Energy Rev*. 2007;11(1364):1584-1595. doi:10.1016/j.rser.2005.11.005
17. Diakoulaki D, Antunes CH, Martins AG. MCDA and energy planning. *Multiple Criteria Decision Analysis: State of the Art Surveys*. Springer; 2005:859-890.
18. Neves LMP, Martins AG, Antunes CH, Dias LC. Using SSM to rethink the analysis of energy efficiency initiatives. *J. Oper. Res. Soc.*. 2004;55(9):968-975. doi:10.1057/palgrave.jors.2601763
19. Vishnupriyan J, Manoharan PS. Multi-criteria decision analysis for renewable energy integration : a southern India focus. *Renew Energy*. 2018;121:474-488. doi:10.1016/j.renene.2018.01.008
20. Mingers J, Rosenhead J. Problem structuring methods in action. *Eur J Oper Res*. 2004;152(3):530-554.
21. Ebrahimi M, Using soft systems methodology for the analysis of sustainable energy initiatives. 2020;(July):211-232. https://www.igi-global.com/chapter/using-softsystems-methodology-for-the-analysis-of-sustainable-energy-initiatives/259201
22. Antunes CH, Dias L, Dantas G, Mathias J, Zamboni L. An application of soft systems methodology in the evaluation of policies and incentive actions to promote technological innovations in the electricity sector. *Energy Procedia*. 2016;106:258-278. doi:10.1016/j.egypro.2016.12.121
23. British Telecommunications. The role of ICT in reducing carbon emissions in the EU. 2016;(May).
24. Simons G, Research C, Division D. Developing cost-effective solar resources with electricity system benefits. *Support of the 2005 Integrated Energy Policy Report*. California Energy Commission; 2005.
25. Warfield JN. *Science of Generic Design: Managing Complexity through Systems Design*. Iowa State Press; 1994.
26. Ackoff RL. The art and science of mess management. *Interfaces (Providence)*. 1981;11(1):20-26.
27. Lane DC, Jackson MC. Only connect! An annotated bibliography reflecting the breadth and diversity of systems thinking. *Syst Res*. 1995;12(3):217-228.
28. Midgley G. Systems thinking for the 21st century. *Systemic Intervention*. Springer; 2000:1-17.
29. Midgley G. Systemic intervention. *Systemic Intervention*. Springer; 2000:113-133.
30. SEBoK. SEBoK Guide to the Systems Engineering Body of Knowledge; 2014.
31. Von Bertalanffy L. *Organismic Psychology and Systems Theory*. Clark University Press; 1968.
32. Klir GJ. Systems Science in Retrospect and Prospect. *Facets of Systems Science*. Springer; 1991:163-190.
33. Boardman J, Sauser B, System of Systems-the meaning of. In: 2006 IEEE/*SMC International Conference on System of Systems Engineering*.; 2006:6.
34. GSMA. Tower Power Africa : Energy Challenges and Opportunities for the Mobile Industry in Africa. 2014;(September).
35. Carita Tissari da Costa. Energy Service Companies Are the Future for African Telecom 3 Power.; 2017. https://www.itnewsafrica.com/2017/11/energy-service-companies-are-the-future-for-african-telecom-tower-power/
36. Event DT. ESCO Roundtable Borderless. 1-21.
37. Abbott R, Emergence explained: getting epiphenomena to do real work. Feb. *arXiv Prepr cs/0602045*. 2006.
38. Rosenhead J. What's the problem? An introduction to problem structuring methods. *Interfaces (Providence)*. 1996;26(6):117-131.
39. Rosenhead J. Introduction: old and new paradigms of analysis. *Ration Anal a Probl world*. 1989:1-20.
40. Mingers J, Rosenhead J. *Rational Analysis for a Problematic World Revisited*. John Wiley and Sons Ltd; 2001.
41. Rosenhead J. Past, present and future of problem structuring methods. *J. Oper. Res. Soc.*. 2006;57(7):759-765.
42. Pohekar SD, Ramachandran M. Application of multi-criteria decision making to sustainable energy planning—a review. *Renew Sustain Energy Rev*. 2004;8(4):365-381.
43. Belton V, Ackermann F, Shepherd I. Integrated support from problem structuring through to alternative evaluation using COPE and V·I·S·A. *J Multi-Criteria Decis Anal*. 1997;6(3):115-130.
44. Checkland P, Poulter J. *Learning for Action: A Short Definitive Account of Soft Systems Methodology and Its Use, for Practitioners, Teachers and Students*. John Wiley and Sons Ltd; 2006.
45. Jackson MC. Deeper complementarism: a brief response to Ulrich. *J. Oper. Res. Soc.*. 2003;54(11):1225-1226.
46. Checkland P. *Systems Thinking, Systems Practice. illustrate. the University of Michigan*. Wiley; 1981.
47. Fielden D, Jacques JK. Systemic approach to energy rationalisation in island communities. *Int. J. Energy Res.*. 1998;22(2):107-129.
48. Checkland P. The development of systems thinking by systems practice-a methodology from an action research program. *Prog Cybern Syst Res*. 1975;2:278-283.
49. Checkland P, Scholes J, Soft Systems Methodology in Action.; 1990.
50. Georgiou I. Messing about in transformations: structured systemic planning for systemic solutions to systemic problems. *Eur J Oper Res*. 2012;223(2):392-406.
51. Georgiou I. Making decisions in the absence of clear facts. *Eur J Oper Res*. 2008;185(1):299-321.
52. Staadt J. The cultural analysis of soft systems methodology and the configuration model of organizational culture. *SAGE Open*. 2015;5(2):215824401558978. doi:10.1177/2158244015589787
53. Bell S, Berg T, Morse S. Towards an understanding of rich picture interpretation. *Syst Pract Action Res*. 2019;32(6):601-614. doi:10.1007/s11213-018-9476-5
54. Hobbs BF, Horn GTf. Building public confidence in energy planning: a multimethod MCDM approach to demand-side planning at BC gas. *Energy Policy*. 1997;25(3):357-375.
55. Checkland P. soft systems methodology: a thirty year retrospective. *Syst Res Behav Sci*. 2000;17:11-58. doi:10.1002/1099-1743(200011)17:1+⟨::AID-SRES374⟩3.0.CO;2-O
56. Flood RL. A brief review of Peter B. Checkland's contribution to systemic thinking. *Syst Pract Action Res*. 2000;13(6):723-731.
57. Tsouvalis C, Checkland P. Reflecting on SSM: the dividing line between 'real world'and 'systems thinking world. *Syst Res*. 1996;13(1):35-45.
58. Checkland P, Tsouvalis C. Reflecting on SSM: the link between root definitions and conceptual models. *Syst Res Behav Sci Off J Int Fed Syst Res*. 1997;14(3):153-168.
59. Mahdi IM, Alreshaid K. Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP). *Int J Proj Manag*. 2005;23(7):564-572.
60. Saaty TL. Group decision making and the AHP. *The Analytic Hierarchy Process*. Springer; 1989:59-67.
61. Naicker P, Thopil GA. A framework for sustainable utility scale renewable energy selection in South Africa. *J Clean Prod*. 2019;224:637-650. doi:10.1016/j.jclepro.2019.03.257

How to cite this article: Ceriano M, Lalk J, Thopil GA. Energy planning in sub-Saharan African telecom networks: Decision support using a soft systems methodology. *Systems Engineering*. 2023;1-12. https://doi.org/10.1002/sys.21706

AUTHOR BIOGRAPHIES



Mbiika Ceriano was born in Uganda in 1985. He received a B.Eng. degree in Telecommunications Engineering (1st Class Honors) from Kyambogo University, Uganda in 2010 and MSc in Telecommunications Engineering (Thesis Cum laude/Distinction) from the Universita' Studi Di Trento (University of Trento), Italy in 2013. He was a PhD candidate with the Graduate School of Technology Management, University of Pretoria. His research interests included energy management, sustainability, system approaches, technology management and telecommunications engineering. He was also an assistant lecturer at Kyambogo University, Electrical and Electronics department in Uganda.

Jörg Lalk is a registered professional electrical engineer with engineering degrees from the Potchefstroom University for CHE (BSc and BEng Hons), University of Pretoria (MEng) and Cranfield University (PhD) and member of INCOSE. He is a past-president of INCOSE South Africa Chapter (2005, and 2019–2020), and a past INCOSE Associate-Director for Technical Review (2015–2018), He held various senior management and systems engineering positions in aerospace and armored systems, ICT systems, energy and business consulting. He currently works with the University of Pretoria's Department of Engineering and Technology Management, Graduate School of Technology Management at the University of Pretoria where he focuses on systems engineering and energy research.

George Alex Thopil is a registered professional engineer with a Bachelor's and Master's degree in electronic engineering from VTU, India and Stellenbosch University, respectively. He holds a PhD in engineering management with a focus on energy and environmental policy, from the University of Pretoria. He is a former chair (2014–2017) of the Engineering Management Society, South Africa chapter. He is a member of IEEE and a senior member of SAIEE. He works with the University of Pretoria's Department of Engineering and Technology Management, Graduate School of Technology Management at the University of Pretoria where his research focus is mainly primarily in the field of sustainable management and engineering economics.