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A Triple Nexus Water-Energy-Housing (WEH) Framework Modelling towards Improved Decision-Making in Humanitarian Operations

Anicet Adjahossou

Department of Systems Engineering, Colorado State University, Fort Collins, USA
Email: anicet.adjahossou@colostate.edu

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Abstract

Given the challenges facing most humanitarian operations worldwide, a change of approach is needed to ensure greater sustainability of humanitarian settlements right from the planning stage. Some studies attribute unsustainability to inadequate provision of basic resources and highlight the apparent bottlenecks that prevent access to the meaningful data needed to plan and remedy problems. Most operations have relied on an "ad hoc ism" approach, employing parallel and disconnected data processing methods, resulting in a wide range of data being collected without subsequent prioritization to optimize interconnections that could enhance performance. There have been little efforts to study the trade-offs potentially at stake. This work proposes a new framework enabling all subsystems to operate in a single system and focusing on data processing perspective. To achieve this, this paper proposes a Triple Nexus Framework as an attempt to integrate water, energy, and housing sector data derived from a specific sub-system within the overall system in the application of Model-Based Systems Engineering. Understanding the synergies between water, energy, and housing, Systems Engineering characterizes the triple nexus framework and identifies opportunities for improved decision-making in processing operational data from these sectors. Two scenarios illustrate how an integrated platform could be a gateway to access meaningful operational data in the system and a starting point for modeling integrated human settlement systems. Upon execution, the model is tested for nexus megadata processing, and the optimization simulation yielded 67% satisfactory results, demonstrating that an integrated system could improve sustainability, and that capacity building in service delivery is more than beneficial.

Keywords

Humanitarian Settlement, Nexus Framework, Water, Energy, Housing, Sustainability, Systems Engineering (SE), Model-Based Systems Engineering (MBSE), Systems Modeling Language (SysML)

1. Introduction

Over the years, there has been observed duplication of efforts in delivering water, energy and housing services, and a form of "ad hoc-ism" whereby sector-specific data is collected and then forgotten or stored in an inaccessible manner, resulting in wasted time and duplication of efforts when planning for subsequent years [1]. In October 2023, a household survey [2] conducted in two Kenyan refugee settlements revealed significant needs among residents. Despite receiving an average of 17 liters of water per person per day, 75% of households required more water for various purposes, including home construction. Only 33% could afford to pay for extra water. Additionally, half of the households needed more energy resources, with 83% able to pay for energy needed for economic activities, as shown in **Figures 1-3**.

These results reveal significant disparities between planning data and achievements. As operational data is collected in an isolated and scattered way, standards are often unmet, and people find alternatives to compensate for shortcomings or make substitutions. They also show that the challenges of transitioning human settlements in a more sustainable direction are enormous and require urgent solutions.

Indeed, the accelerated nature of displaced population growth predicts ever-increasing pressure on water, energy, and housing, which is likely to lead to resource depletion, degradation of ecosystem services, and irreversible societal and environmental changes in the long term. Quantifying the interconnections between the energy, water, and housing sectors is a first step towards integrated systems modeling that would contribute to a sustainable and integrated planning of humanitarian settlement. To date, the literature shown that little work has been done to investigate the interlinkages between water, energy, and housing in the humanitarian context, where each sector is still perceived and operated separately. The effectiveness of water sub-system options for improving resource efficiency to reduce gaps is only examined at the water's edge. Similarly, the efficiency of energy supply is only studied from an energy needs perspective [3], while the efficiency of housing construction is only perceived as the need for capping a shelter. As a result, important gaps have emerged along the way. The current provision of energy supply had unintended consequences that affected the well-being of displaced populations, as experienced in refugee settlements in Kenya located in an arid region prone to frequent and prolonged droughts. The various options for remedying the water shortage required considerable energy to operate the solar energy system, with further consequences for energy supply and *vice versa*. Similarly, constructing permanent houses induces high domestic water consumption, affecting the water supply. This situation continues to be a

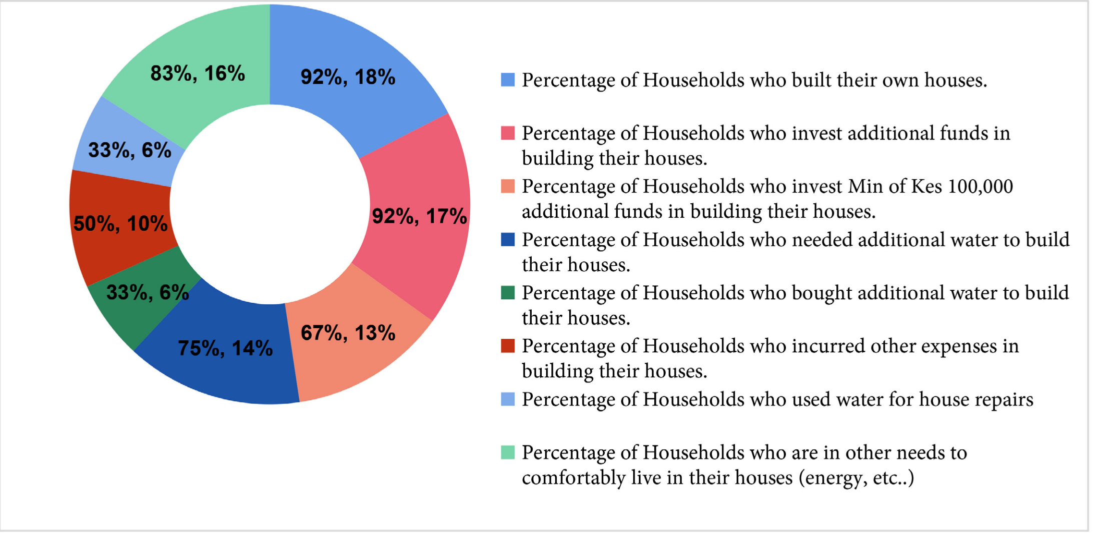

Figure 1. Household water consumption in kenyan refugee settlements (October 2023).

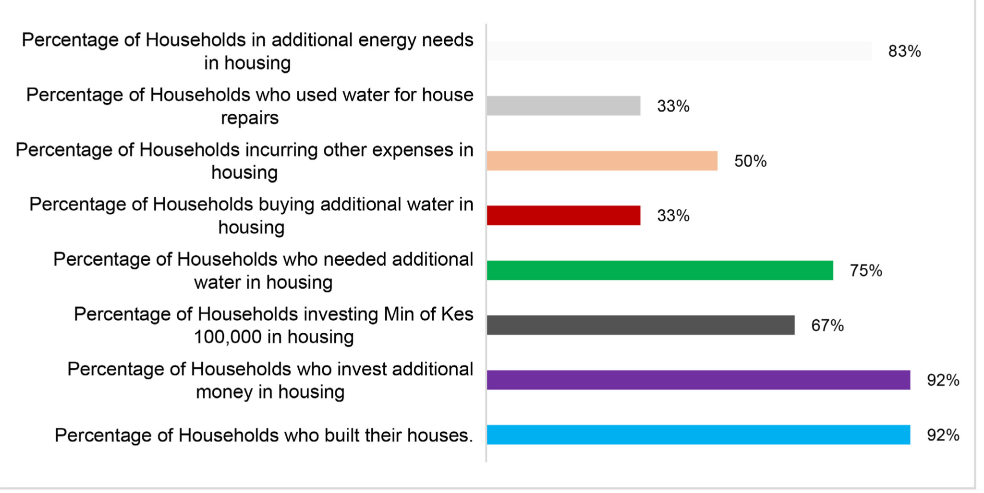

Figure 2. Household houses construction in kenyan refugee settlements (October 2023).

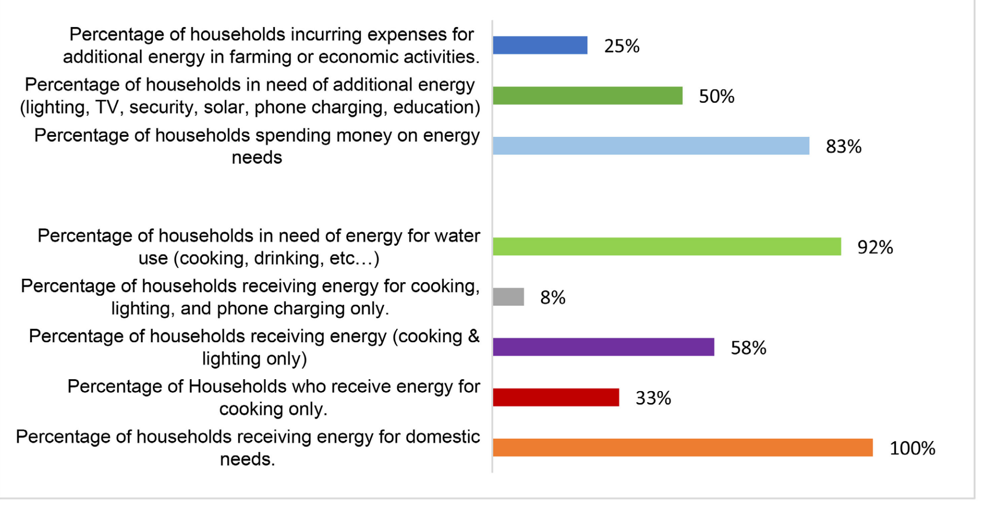

Figure 3. Household energy consumption in kenyan refugee settlements (October 2023).

daily occurrence and justifies the present study. Among the issues and challenges that could be the cause is the growing refugee population.

While only 22% of refugees currently live in unplanned human settlements, many will live in urban-type settlements by 2050 [4]. This population increase generates negative consequences and externalities that will affect the quality of life in humanitarian settlements, such as inequitable access to basic social services, water scarcity and contamination due to floods, droughts, forest depletion, conflicts, climate change exacerbation and overexploitation of natural resources. Population growth also means that more will need basic services, more sustainable and affordable infrastructure systems will be required, such as energy, water, housing, food, more people will need health services, more educational institutions will be in demand, and so on. All these factors cause challenges for the sustainable development of human settlements and increase the complexity of managing human settlements. With such a boom in urbanization and associated challenges, there is a need to adopt an integrated system approach that would align the triple nexus framework to ensure the sustainable development of humanitarian settlements.

This work examines the relevance of shortcomings in the current practices and proposes a novel Triple Nexus Framework which would make it possible to better organize and integrate data from water, energy, and housing sectors by applying Model-Based Systems Engineering (MBSE) methodology. The ultimate outcome is to introduce a novel model-driven approach in humanitarian operations that would have potential to significantly affect the design and management of refugee settlements towards more sustainable practices, aligning with current global priorities.

2. Nexus Approach in Humanitarian Operations—A Literature Review

While few studies have examined the sustainability of the nexus of water, energy, and housing in social systems, some scholars have conducted research in specific areas that complement this research. Yasmin *et al.* [5] has explored a systematic review of water, sanitation, and hygiene sustainability and resilience in refugee communities. They found that there are growing concerns about the sustainability of water, sanitation, and hygiene, which depends on understanding the roles and interdependences between factors, and that there is a need to recognize that there is no one-size-fits-all solution. Similarly, Yilin Zhuang [6] conducted a study on integrating water and energy resources (water-energy nexus) through a system dynamics approach. While the study recognizes that water and energy are intrinsically linked and dependent on each other in the modern city, only from the point of view of their management, it did not highlight the importance of the territoriality in which water and energy systems unfold and interact, nor the planning options that could inform various scenarios, and was therefore limited by the lack of meaningful data considerations. To another extent, in investigating the integrated approach to water, energy, and food nexus, Mohammad

Al-Saidi and Nadir Ahmed Elagib [7] attempted to identify possible ways to assess the interdependent resource problems between the three resources using a science and policy framework. They found that although the linkages between water, energy, and food have succeeded in changing political debates, the prioritization of problems is lacking and seems to depend on specific case studies and the choices of political decision-makers. However, it also underscored the urgent need for a more integrated and cross-cutting approach to addressing issues across these three resources. In this respect, it raised the need for a more in-depth analysis of the linkages between the three resources and the issue of governance, which has still not been addressed in the debate.

To understand the integrative perspective that makes a human settlement more sustainable by optimally managing water, energy, and food resources, Maryam Ghodsvali [8] attempted to develop an integrated decision support system through a spatial optimization model that relies on a combination of methods guiding the decision-making process through the modeling and planning of complex systems such as cities. The results could serve as strategic guidelines for policymakers and encourage effective decision-making while minimizing environmental burdens in integrating the water, energy, and food nexus. Fatima Mansour *et al.* [9] more critically examined the issue of increased world population versus exaggerated global resource consumption, resulting in many difficulties. They concluded that a sustainable solution requires a comprehensive review of these resources' availability, affordability, quality, and stability, and the adoption of the water-energy-food nexus as a key pillar of resource allocation and management in cities. The study adopted a multi-criteria approach in identifying linkages between water, energy, and food resources in a holistic and integrated manner rather than as separate components. Thus, the benefit of their approach is that it considers the interconnections between the three resources that efficiently contribute to creating synergy between them. The study concluded that the water-energy-food nexus approach could prevent the transfer of problems from one sector to another through the linkages between them. Ultimately, it offers the advantage of minimizing global trade-offs and maximizing co-benefits that improve overall sustainability [10].

Based on above, several research have been carried out to illustrate nexus concept, for example, in the field of water, energy, and food, sometimes using simulation tools [11], nexus governance [12] or simply judicious implementation [13]. It can be argued that these reflections have contributed to a better understanding of the water-energy-food nexus in general. However, none of the studies has yet presented a critical analysis of the nexus concept in humanitarian contexts through a systems lens. Ringler, A. Bhaduri and R. Lawford [14] who reviews the water-energy-food nexus concept through methodological research questions, recognizes the difficulties associated with data uncertainty and modeling, the underlying mechanism of nexus problems, and system performance assessment. In the same vein and complementing, Ringler *et al.* [15] conducted a sustainability assessment across the water, energy, land, and food nexus by exploring their inter-connectedness. Some results concluded that water, land, and energy resources are all crucial contributors to food security and holistic sustainability could promote investment options that co-balance benefits across different sectors. But again, it does not investigate the root causes that could lead to the inefficient use of these resources, which could be related to poor planning options or the unavailability of meaningful data that would help advance the concept of the water-energy-land and food nexus. Moreover, the context of this study is far from the specific humanitarian situations. By further investigating the dynamics at play within the water-energy-land-food nexus over time, Bernard Amadei [16] has introduced a multi-characteristic concept comprising social, environmental, infrastructural, and economic components and their related elements, in which the linkages between water, energy, land, and food unfold. The study underlined the importance of considering the community for which the nexus is intended, and which must be satisfied with nexus resources such as water, energy, and so on. His work highlighted the importance of dealing with data quality in a participatory and systemic way. He introduced a new method for modeling the nexus, using system dynamics applications to study its different states over time.

With regard to the contribution of the housing sector to the concept of nexus, there are few concrete studies, especially not in humanitarian contexts or underdeveloped community landscapes. Nevertheless, in an attempt to provide an overview of the housing sector's potential effects on the nexus, Ali Cheshmehzangi [17] has analyzed the divergences, challenges, and implications of the energy-housing nexus in China's wealthiest transitional urban and peri-urban areas, as well as in the country's least affluent rural areas. However, the study was limited to the implications of existing housing and energy policy reforms, which have advanced policies to promote green strategies and energy savings in the housing sector. From the perspective of the interconnection of the housing and water sectors, for example, Meehan *et al.* [18] studied the conditions of access to water in the context of housing construction for low-income communities in the USA. The study showed that precarious access to domestic water should be seen as a housing problem reflecting structural inequalities, particularly in cities where wealth gaps are widening to the detriment of low-income populations. In light of this, the study concluded by calling for more research and action at the intersection of water supply, housing, and social inequality, the so-called housing-water nexus. He noted that there is a correlation between water resources and housing and that problems of inequality persist, particularly in low-income areas that lack adequate infrastructure and where this link is not yet well understood. While a few studies have looked at the links between water, energy, land, and food from a rural and urban perspective, a limited number have focused on the sustainability of housing without emphasizing the relationship between water and housing and, even more regrettably, in humanitarian contexts. However, Henry and Grobler [19] conducted a study to establish a relationship between food and housing insecurity in low-income neighborhoods in

South Africa using different statistical techniques based on a quantitative research method. Although the study was not conducted in a typical humanitarian context, it found however that there is a trade-off between housing and food security and that, in many cases, food and housing insecurity coexist. Most importantly, it stated that in any human context, affordable housing and food security are essential for development to ensure an adequate healthy lifestyle. In the same context, Abby Ostovar [20] studied the impact of water conditions on housing development on the Monterey Peninsula. He examined the extent to which water could limit affordable housing development for lower-income households. However, it only scratched the surface of the Monterey Peninsula's housing and water situation and did not describe it in detail, nor did it examine the detailed differences between jurisdictions, how best to implement the recommendations, or what some of the trade-offs would be.

2.1. Data Management in Humanitarian Operations

In the context of humanitarian settlements, data in general can be classified into three categories such as administrative data which includes human resources and the supply chain, financial data, and operational data, which is the focus of this work. Operational data will typically include data on populations and their needs, projects, monitoring and evaluation, and socio-economic data, and so on. **Figure 4** shows the categories of data and illustrates how humanitarian actors process parallel operational data for water, energy, and housing, as an example.

As shown in **Figure 4**, the three sectors of water, energy, and housing, called "triple nexus", process data differently and in parallel. This means that the same data on water, energy, and housing are collected from different sources almost simultaneously, resulting in redundancy and the creation of three separate databases due to a lack of integration that would both interconnect data processing and optimize the setting of meaningful priorities for planning.

The failure to adopt such a systemic approach has led to poor design and unsustainability of humanitarian settlements. Significant shortcomings have emerged since the current disaggregated method generates unintended consequences which negatively affect the well-being of displaced populations. Most of the time, humanitarian partners spend efforts and time collecting and reinterpreting much scattered, isolated, and purpose-driven data. A systematic data integration has not been adequately emphasized; therefore, there is evidence of duplication of effort in some instances of inefficient and poor-quality data management practices [21]. In short, there is a preponderance of sector-specific data and a duplication that negatively affects the sustainability in humanitarian settlements.

As such, the United Nations recognize the need for a decision-support framework that could integrate and systematize data from a different sector through a unified data platform rather than the conventional methods as outlined in the literature.

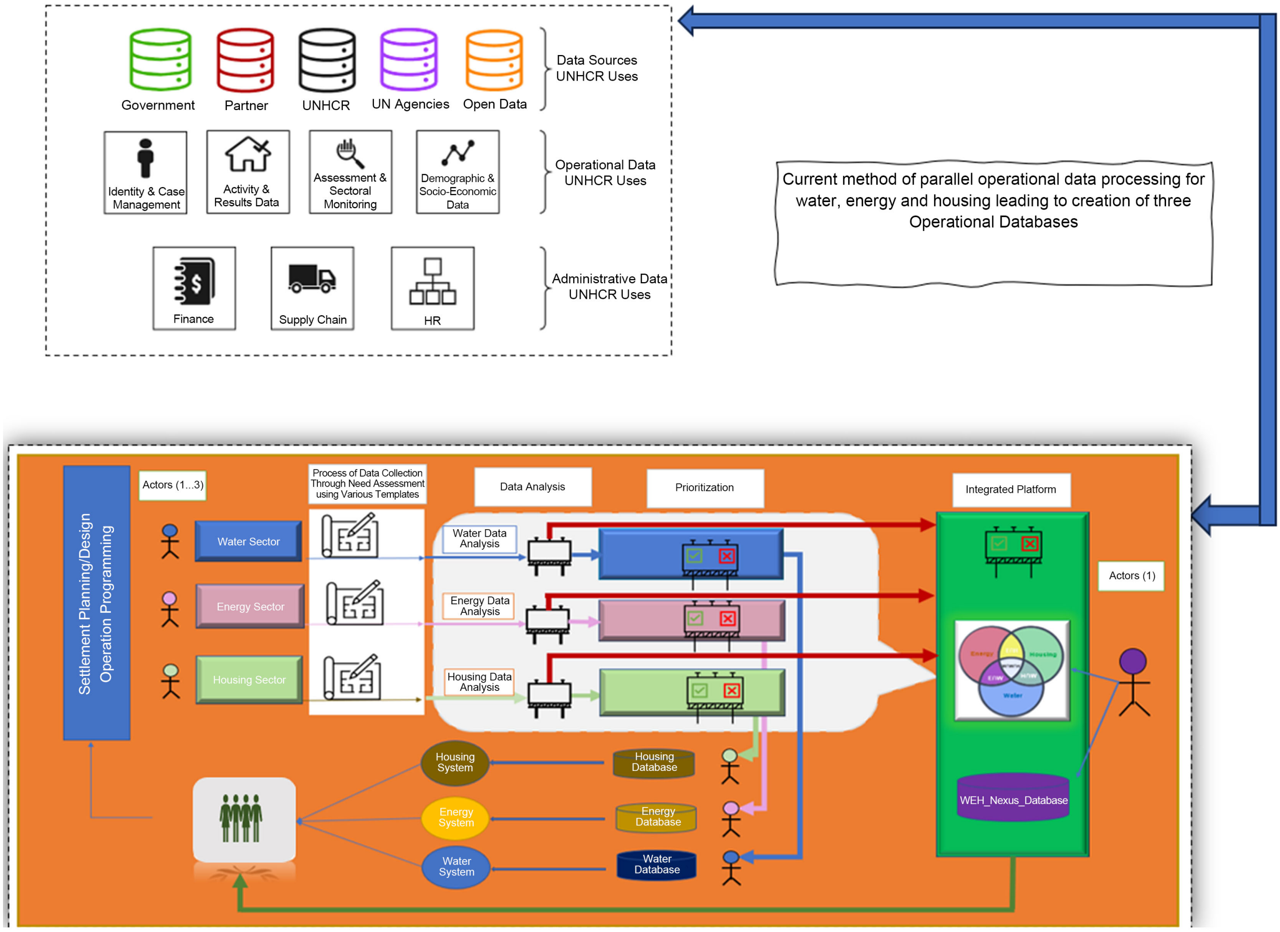

Figure 4. Operational data types showing a decentralized processing of water, energy, and housing data [Adapted from [21]).

2.2. Access to Water, Energy and Housing in Humanitarian Settlements

Access to water is vital for displaced people. However, more than half the world's refugees cannot access the minimum required quantity. United Nations High Commissioner for Refugees estimates that more than half the world's refugee settlements do not have enough water to meet the recommended 20 liters per person per day [22], and according to the 2023 global Water Security Assessment report [22], 78% of the world's population currently lives in countries without guaranteed access to water. Moreover, the report revealed that the world's population will reach around 10 billion by 2050, of which around 4 billion will live in water-stressed basins. On the other hand, growth in global energy demand is relatively modest due to the widespread deployment of energy-efficient technologies and the global economy's transition to services. However, demand is still expected to increase by about 37% by 2040 [23]. Most refugees rarely have access to suitable energy sources, and it is estimated that 80% of the 8.7 million displaced people use traditional biomass for cooking and have no access to electricity. They depend mainly on the forests nearby for firewood. As a result, hectares of forest are cleared and burned yearly in areas close to refugee settlements [23]. Limited access to energy resources in settlements negatively impacts the sustainability and safety of displaced populations. While equitable and safe access to clean and affordable energy is closely linked to the enjoyment of needs associated with water, housing, and education, this still constitutes a major challenge in most settlements, as previously outlined.

Furthermore, access to long-term, safe, and affordable housing is an ongoing quest for displaced people. According to the United Nations High Commissioner for Refugees, around 30% of refugees are housed in self-settled settlements, forced to live in substandard and unsanitary housing conditions. Refugees in urban areas also face similar challenges in informal and unplanned settlements. Fewer than 20% have access to real housing that complies with norms and standards and is supplied with sufficient water and energy. Indeed, water, energy, and housing are intrinsically interrelated, and the provision of one generally depletes the resources of the other two and *vice versa*, due to the environment that produces them and the institutional arrangements in place. In most humanitarian settlements, these three sectors' important decisions are generally uncoordinated. For instance, energy policies typically rely on the idealistic assumption of abundant water for potential energy solutions. Still, today's dynamic, urbanized, and interconnected context leaves little room for such fragmented governance. The interlinkages between energy, water and housing influence the extent to which the system's sustainability can be achieved.

The Triple Nexus approach of water, energy, and housing is a holistic sustainability view that seeks to determine a balance between different sectors. However, today, the three sectors' planning, allocation, and management approaches are still largely decentralized.

As illustrated above, limited efforts have so far, been undertaken to pool the benefits of data integration. For example, the effectiveness of water supply options to improve consumption and reduce shortfalls is only examined from a water perspective, and energy production requirements for domestic and commercial activities are only estimated from an energy perspective. Similarly, energy production requirements for domestic and commercial activities are only calculated from the energy point of view. At the same time, the efficiency of housing construction is mainly perceived from the product point of view. As a result, significant gaps have emerged in practice over time, as highlighted in the UNHCR evaluation report [21]. The current approach in the planning for energy supply has had unintended consequences that affect the well-being of refugees, as is the case in refugee settlements in Kenya [24]. In these settlements in an arid region of Kenya prone to frequent and prolonged droughts, the various options for remedying the water shortage require considerable energy to operate the solar-powered system, affecting the energy supply and *vice versa*. Similarly, building sustainable homes requires a considerable amount of water, which affects the water supply system often designed for domestic water supply. This situation, which stems from an isolationist approach to the design of these systems, continues today.

The main objective of this work is to develop a typical and practically generalizable model of sustainable humanitarian settlement for which a data processing framework is incorporated to address the main limitations, uncertainties, and challenges relating to the current mode of planning with the support of MBSE and SysML from the new wave of systems engineering, and the underlying advanced data integration applications.

2.3. Theory of the Triple Nexus: Water-Energy-Housing (WEH)

The Triple Nexus approach derives from the need for water, energy, and housing integration as they are closely interlinked (see **Table 1**). With the traditional sectoral approach attempting to achieve sustainability of resources and services independently often jeopardizes the sustainability of one or more other sectors. The Triple Nexus approach enables the realization of interlinkages, synergies, and trade-offs to identify solutions, foster water-energy-housing integration, sustainability, and efficiency, and reduce impacts and risks on the urban planning subsystem in the settlement.

The Triple Nexus Water-Energy-Housing (WEH) approach originated as to how to deliver water, energy, and housing for all integrated into a specific subsystem within the overall system. From the literature review and the survey carried out in refugee settlements in Kenya, the Triple Nexus WEH approach moves beyond the traditional sectoral approach to achieve overall sustainability in the settlement. While the current approaches remain decentralized, the Triple Nexus approach identifies mutually beneficial responses based on understanding the synergies between water, energy, and housing properties and policies. It also provides an informed and transparent framework for determining trade-offs and synergies that maintain the integrity and sustainability of the settlement system in which it unfolds. The Triple Nexus is a generalizable framework defined as a gateway to using composite data in setting priorities for multi-sector programming.

Table 1. Multi-Dimensional interlinkages between water, energy, and housing (Adapted from [25]).

Water <-> Energy: Water plays a key role in energy production, for irrigation, in hydroelectric plants, for cooling thermal (fossil-fuel or nuclear) plants and in growing plants for biofuels. Conversely, energy is required to process and distribute water, power water supply equipment (solarization), pump and treat groundwater, etc.
Water <-> Housing: Water is the keystone for housing construction and repairs, housing needs, concrete and bricks production, etc. Conversely, agricultural intensification for households' activities impacts water quality.
Housing <-> Energy: Energy is essential to life and comfort in the home. It is needed for lighting, heating, cooking, and income-generating activities. It is an input throughout the home's construction, from pumping water to processing, transporting, and refrigerating food in the house.
Integration between water, energy, and housing is an essential requirement for the sustainability of all the above. It is negatively affected if water, energy, or housing are unsustainable within the urban planning subsystem and the integrated human settlement.

3. Methodology and Process

This paper applies Model-Based Systems Engineering (MBSE) and Systems Modeling Language (SysML) as most appropriate applications capable of organizing and consolidating data across diverse sectors through a unified platform to shed light on the complex interdependencies that exist between them. MSBE methodology has the potential to realize and manage complexities over diverse elements within a system such as a human settlement to overcome the decentralized approaches or methods as being experienced in practice today.

This work uses MSBE methodology to develop a Triple Nexus Framework aiming to organize and integrate data on the water, energy, and housing sectors better, which would contribute to the sustainability of the overall system. The Nexus platform is the final stage in the process: the consolidation and access to the set of meaningful integrated data to consumers. At the Nexus level, data from the three sectors are integrated and processed according to the planning objectives. Figure 5 below presents the schematic representations of the Triple

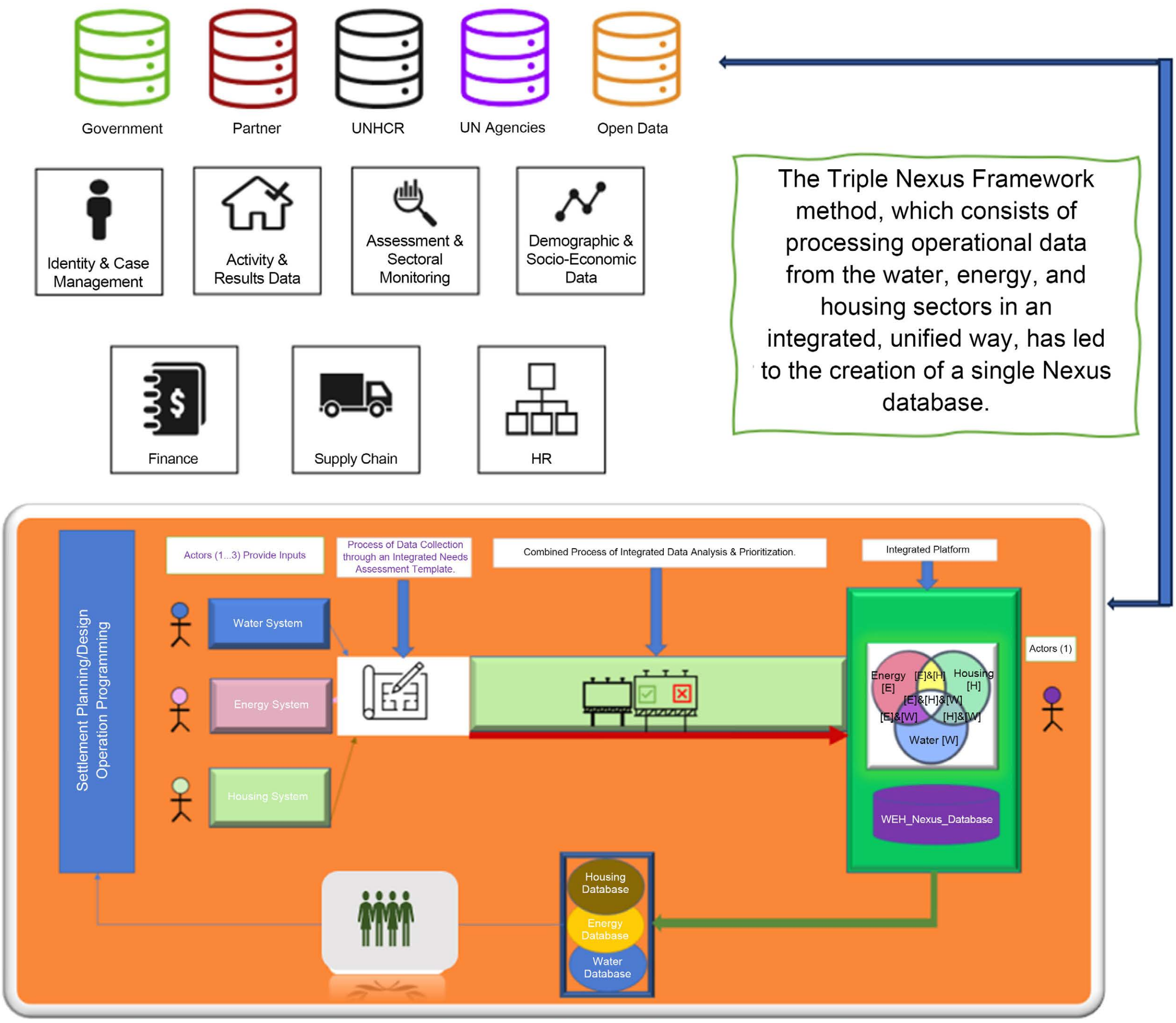

Figure 5. Schematic representation of the triple nexus processing.

Nexus Framework processing and operations. As shown in **Figure 5**, data from the three sectors of water, energy, and housing are processed, analyzed, consolidated, and prioritized through a single process and in a single direction. The processing of the building composite data or indicators that link interrelated properties to all three sectors aims to optimize common benefits. A single Nexus database and centralized platform are then created to store all data simultaneously and make it available to stakeholders as required.

4. Research Results

4.1. Modelling the Triple Nexus

The importance of the Triple Nexus stems from the challenges and problems revealed in the surveys carried out in refugee settlements in Kenya [2]. This work demonstrates that the three sectors of water, energy, and housing, defined as the "Triple Nexus", process data differently and in parallel. This implies that the same data generated on water, energy and housing are collected from different sources almost simultaneously and in parallel, resulting in redundancy and the creation of three separate databases due to a lack of integration that should enable interconnection in the data processing. This would considerably optimize system performance by setting more rational priorities for planning. This new data processing framework also makes it possible to develop composite data across the three sectors, which has been widely recommended in recent years by most stakeholders for including multi-sector indicators in operations planning and management. **Figure 6** shows the Triple Nexus Framework developed using MBSE methodology.

This work determines that the lack of a systemic approach to data processing, particularly to the Triple Nexus, has often led to poorly design and unsustainable humanitarian settlements.

4.2. Triple Nexus Platform Design

For this study, Urban Planning is the sub-system from which the Nexus data of the triple Nexus water, energy and housing is derived. The Nexus platform is the final stage in processing the nexus data, which is then verified and consolidated before being made available to users. At the Nexus level, data relating to the three sectors of water, energy, and housing, are processed, and recomposed according to expected results. Thus, following the same system-wide process, data from the three sectors that make up the Water, Energy and Housing Nexus are collected from external sources, analyzed, combined, processed, and transferred to an integrated platform, as shown in **Figure 7** below, for users in the planning of settlements. Upon completion of the Triple Nexus Framework as shown in **Figure 7**, the model was tested on its capacity to process Nexus data following the new approach, and the optimization simulation results are shown in the below sessions (**Figure 8**).

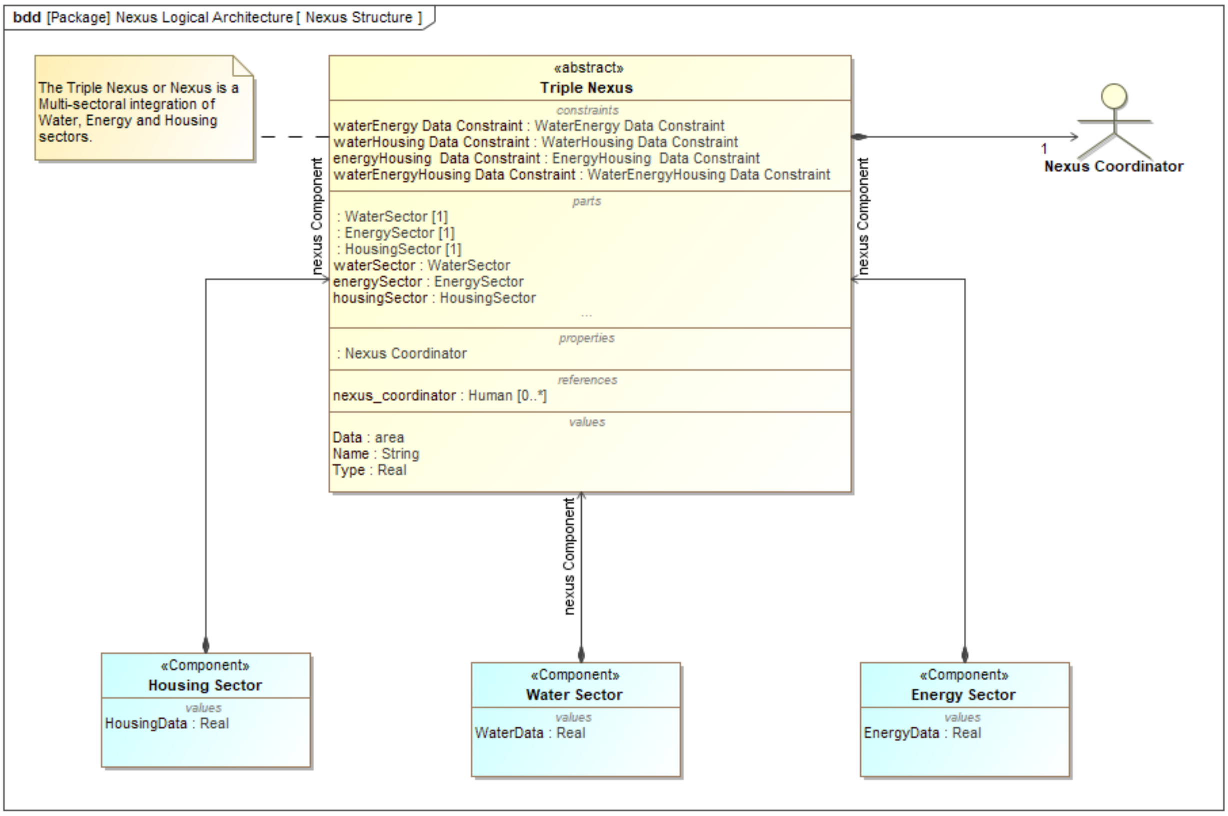

Figure 6. SysML block definition diagram showing the nexus framework structure.

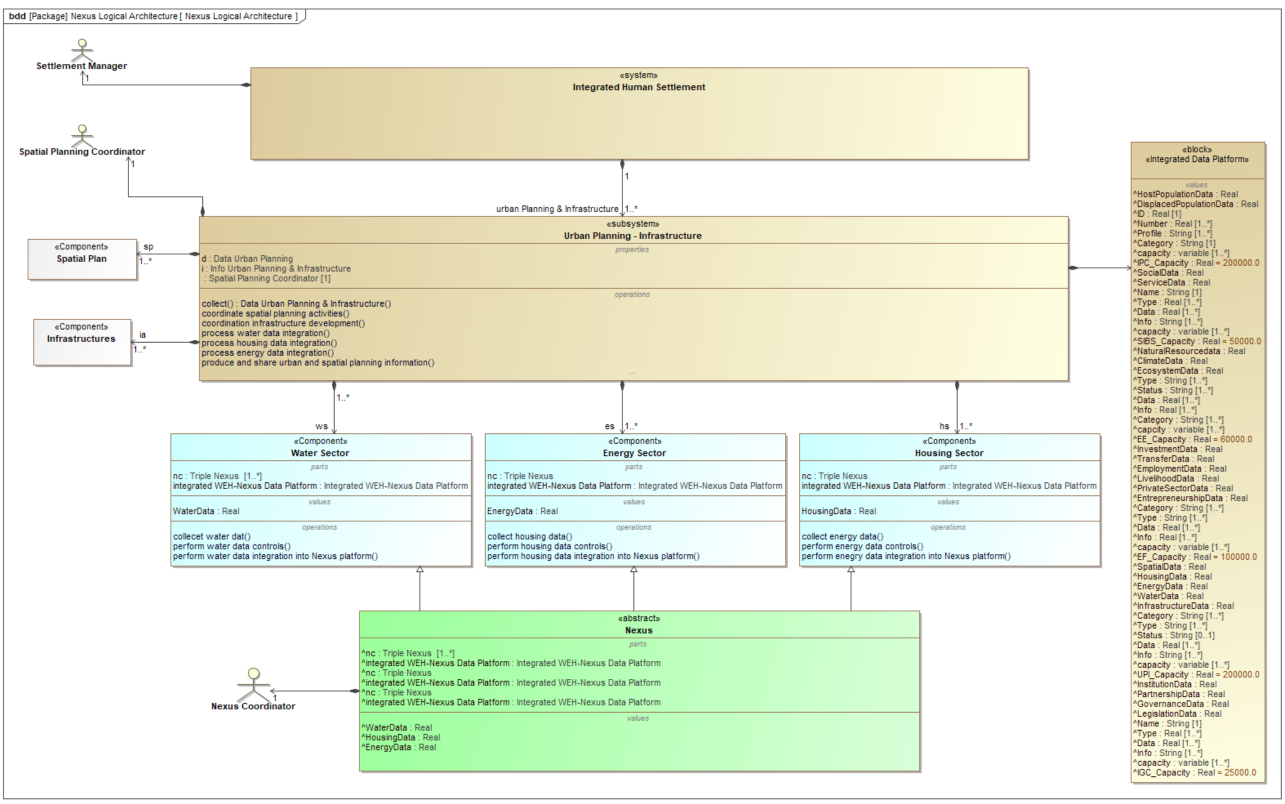

Figure 7. SysML block definition diagram of the nexus integrated data platform.

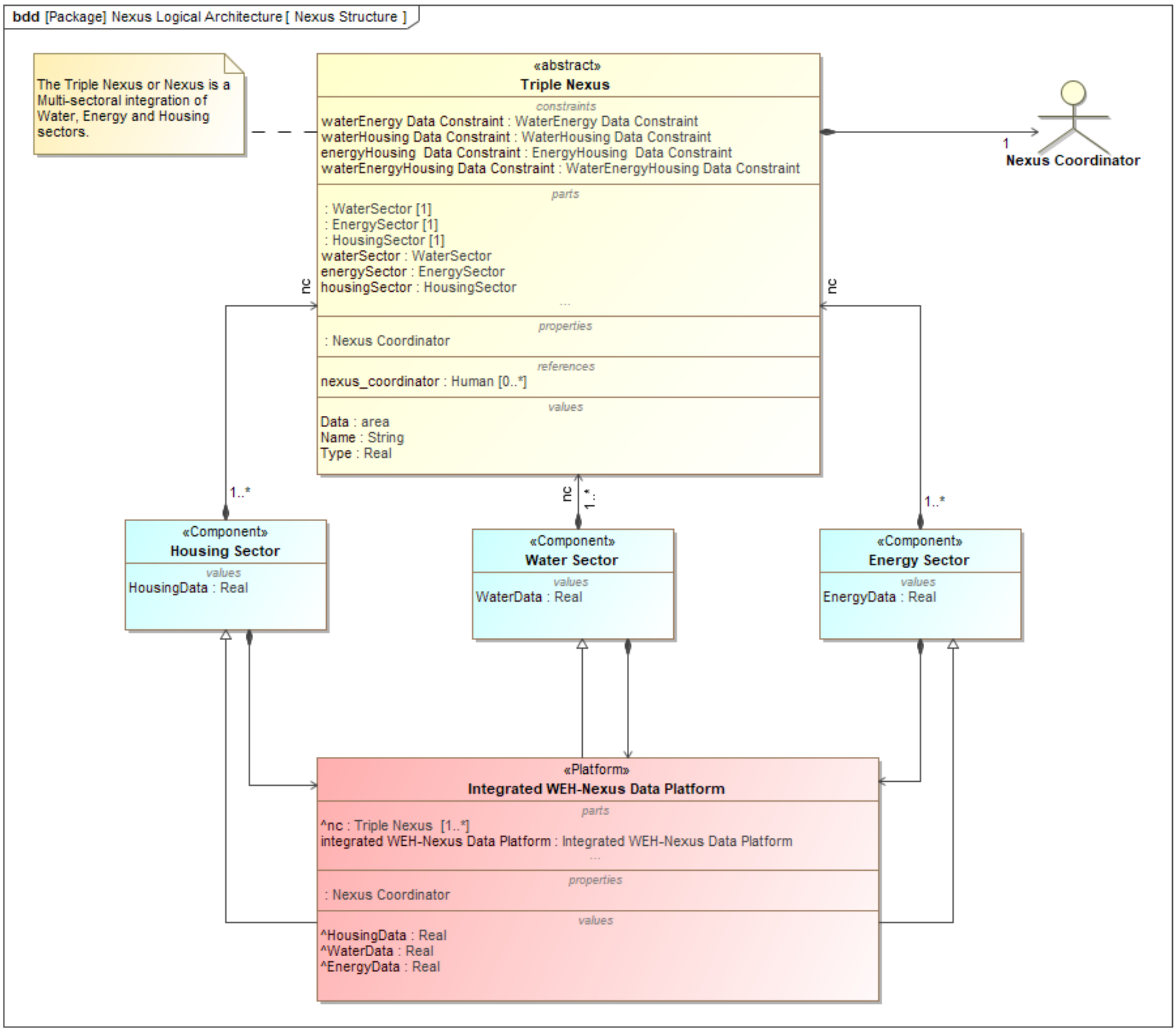

Figure 8. Simplified SysML block definition diagram of the nexus integrated data platform.

Figure 9 below shows a high-level illustration of the proposed Triple Nexus model. The diagram shows states through which the Nexus system of an integrated human settlement system goes through in its operations. The sources of data will be the starting point through which data is produced by several means such as sensors, cloud-sourcing, etc. Data will then be sourced and stored at the level of data block presented as a Nexus data platform. At this level, data will be processed into meaningful information stored by the information block presented as the Nexus information platform (**Figure 9**).

4.3. Triple Nexus Optimization

The objective of the Triple Nexus optimization is to demonstrate the data processing improvement between the humanitarian current approach, and the Nexus proposed approach through model simulation. As shown on **Figure 10**, optimization analysis process is executed for the Triple Nexus data processing.

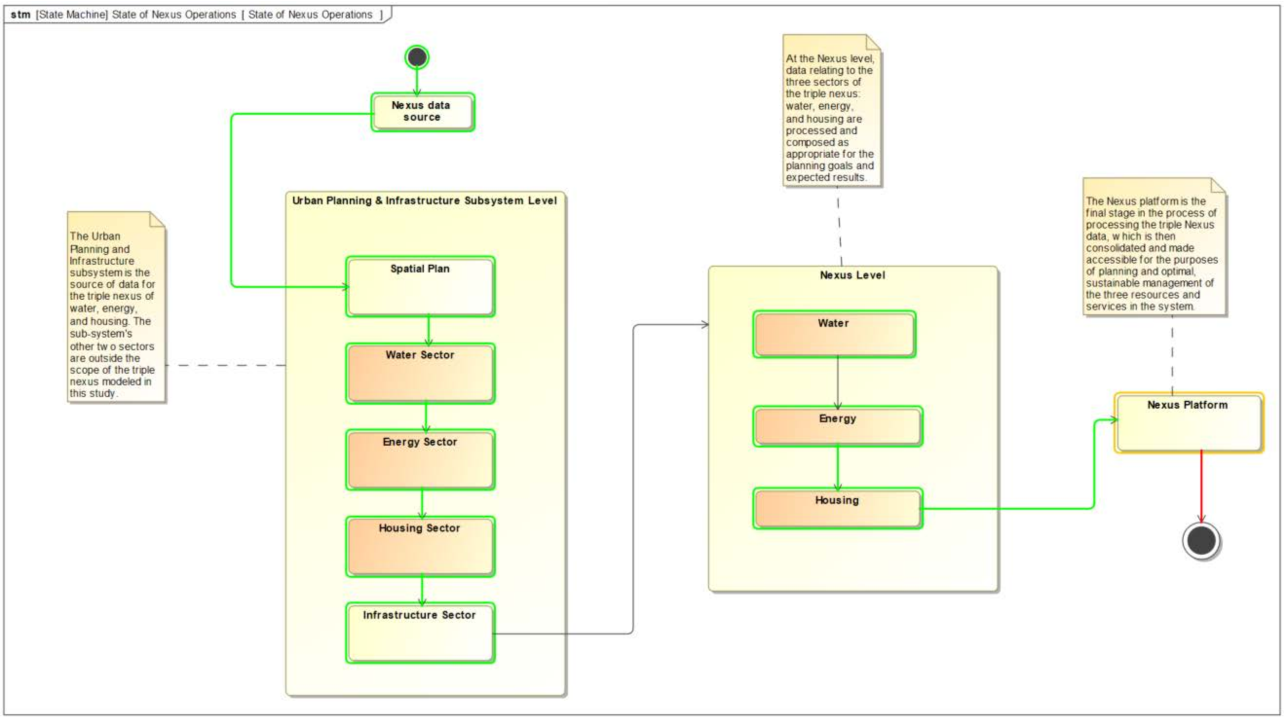

Figure 9. SysML state machine high level illustration of the triple nexus operations.

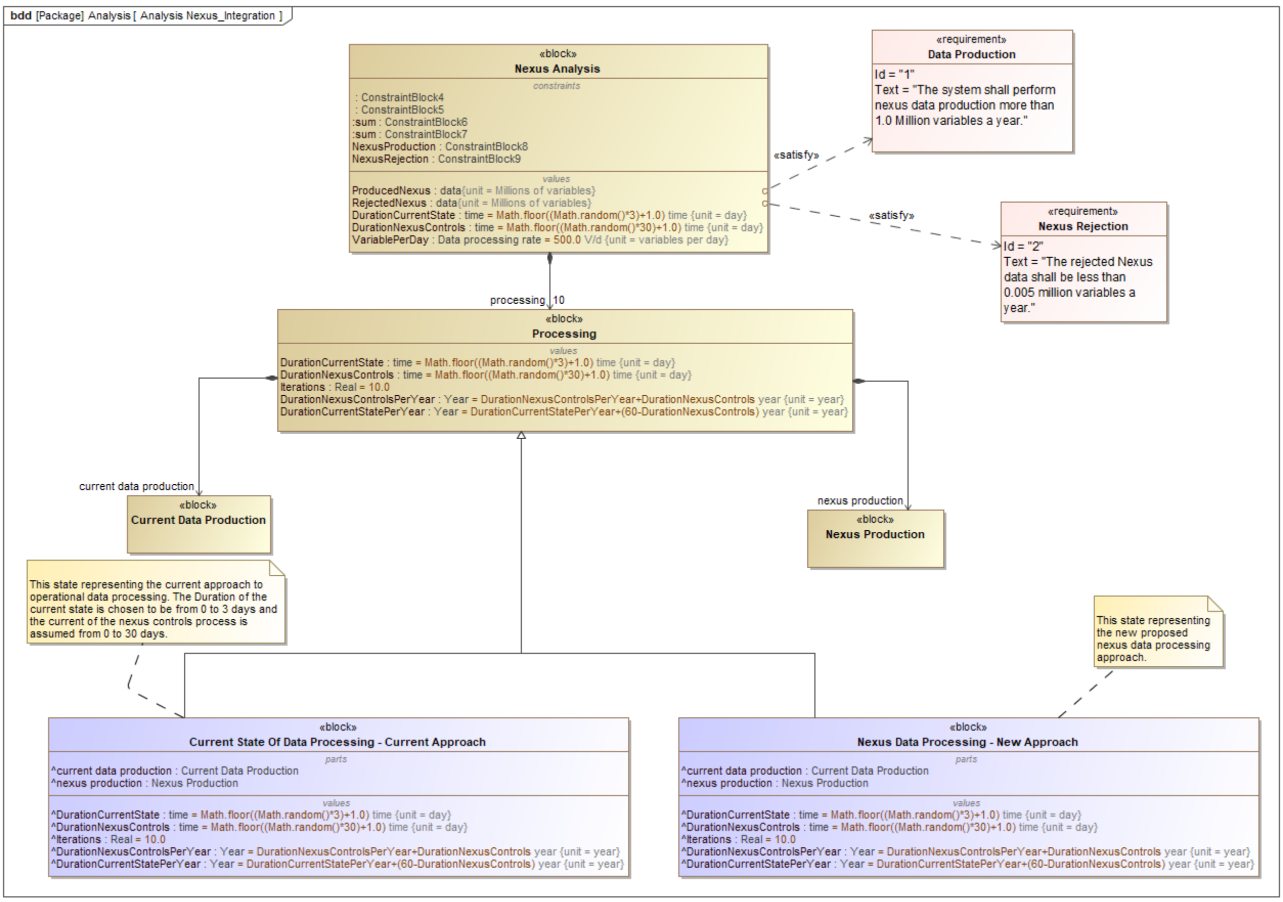

Figure 10. SysML block definition diagram showing the triple nexus data processing operations.

There are two parts: 1) Data production based on the current approach and 2) Data production based on the Nexus data integration approach. Data processing is used as part of the Nexus analysis by the two requirements to be satisfied. The next step is to model data processing operations which is executed in the Sequence Diagram shown in Figure 11. The model was executed in 2-month period as an indicative nexus processing cycle (assumption). Thus, up to two months period, it will be simulated the single flow. The model is simulated in a cycle being repeated over a year as shown in the Activity Diagrams (Figure 12 and Figure 13). The Activity Diagrams show the property iteration decrease, the data processing Sequence Diagram and the operation is repeated if Iteration >0. There are also two "Actions" elements which are used to randomize the duration of the current processing (current state) and the duration of the nexus controls processing. The duration of the current state is chosen to be from 0 to 3 days, and the current of the nexus controls process is assumed to be from 0 to 30 days. The second Action of analysis is that the simulation is executed in a year period. So, when one cycle is executed, the total is increased by the cycle in the Action one (Duration of current state and duration Nexus controls).

Upon completion of the simulation, the duration of current approach (state) per year and the duration for Nexus controls per year are executed. There are 2 possibilities for simulation: Current state of data processing (current approach) and Nexus data processing (proposed new approach). The aim is to demonstrate the difference between the current processing performance and the new proposed data processing performance. The Activity Diagram (Figure 13) shows

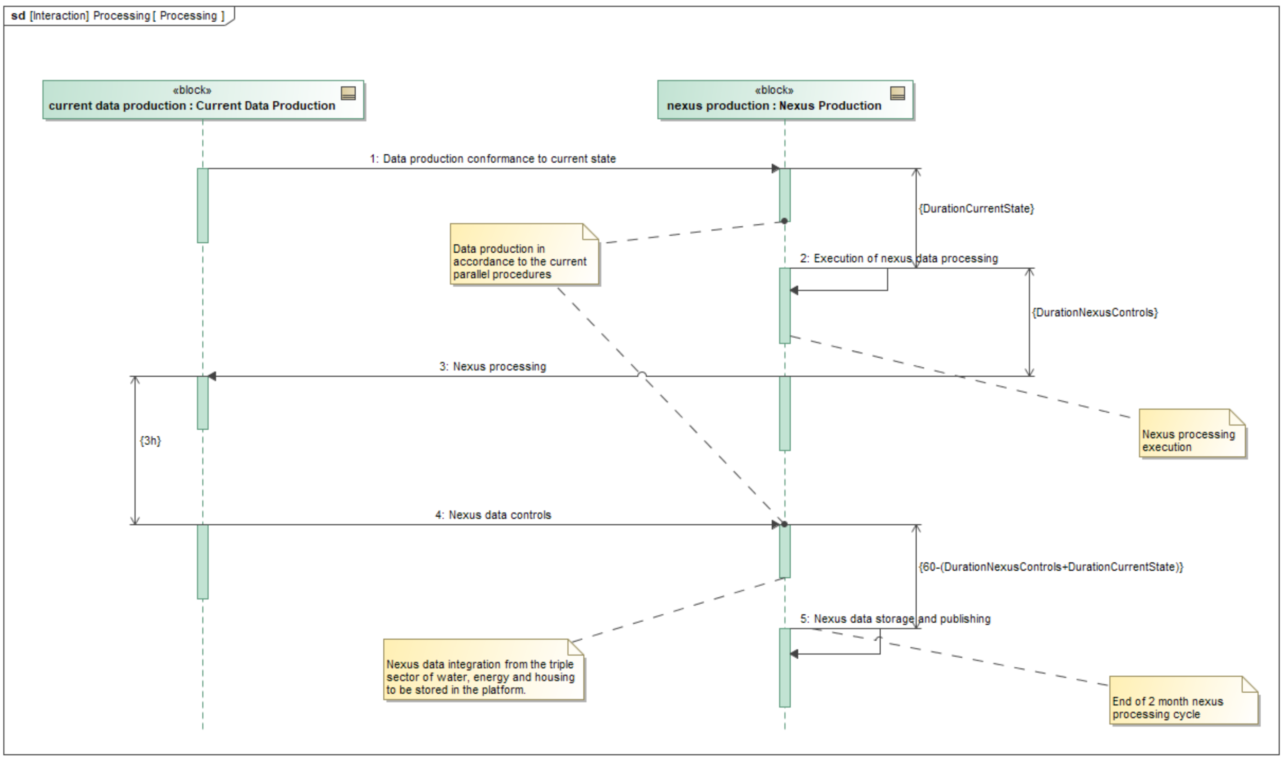

Figure 11. SysML sequence diagram showing data integration process.

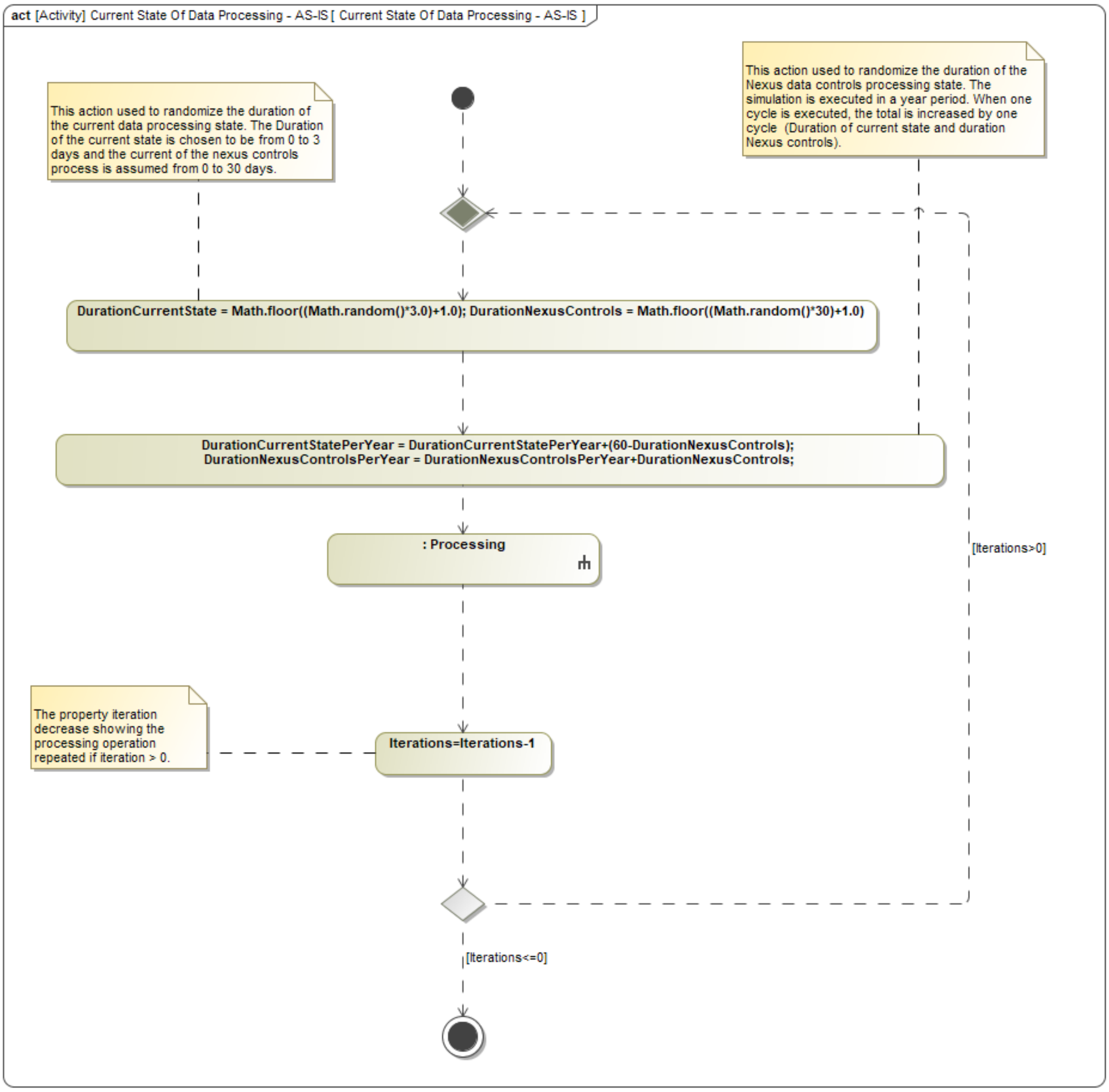

Figure 12. SysML activity diagram showing properties iteration based on the proposed nexus data processing.

the duration of the Nexus execution assumed to be equal to 1 day, while it is assumed to be from 0 to 30 days for the current approach (**Figure 12**). The Sequence Diagram (**Figure 11**) is simulated for all cycle of the year. The Sequence Diagram is used to model the system optimization simulation process. The assumption for the model parameterization is that many data processing could be ongoing at the same time and on a request basis. This is shown by the analysis performed by a number of processing multiplicity assumed at 10, and the execution of the model shows 10 data processing running same time. The execution showed the results of the two configurations and the requirements are satisfied after the 7th simulation.

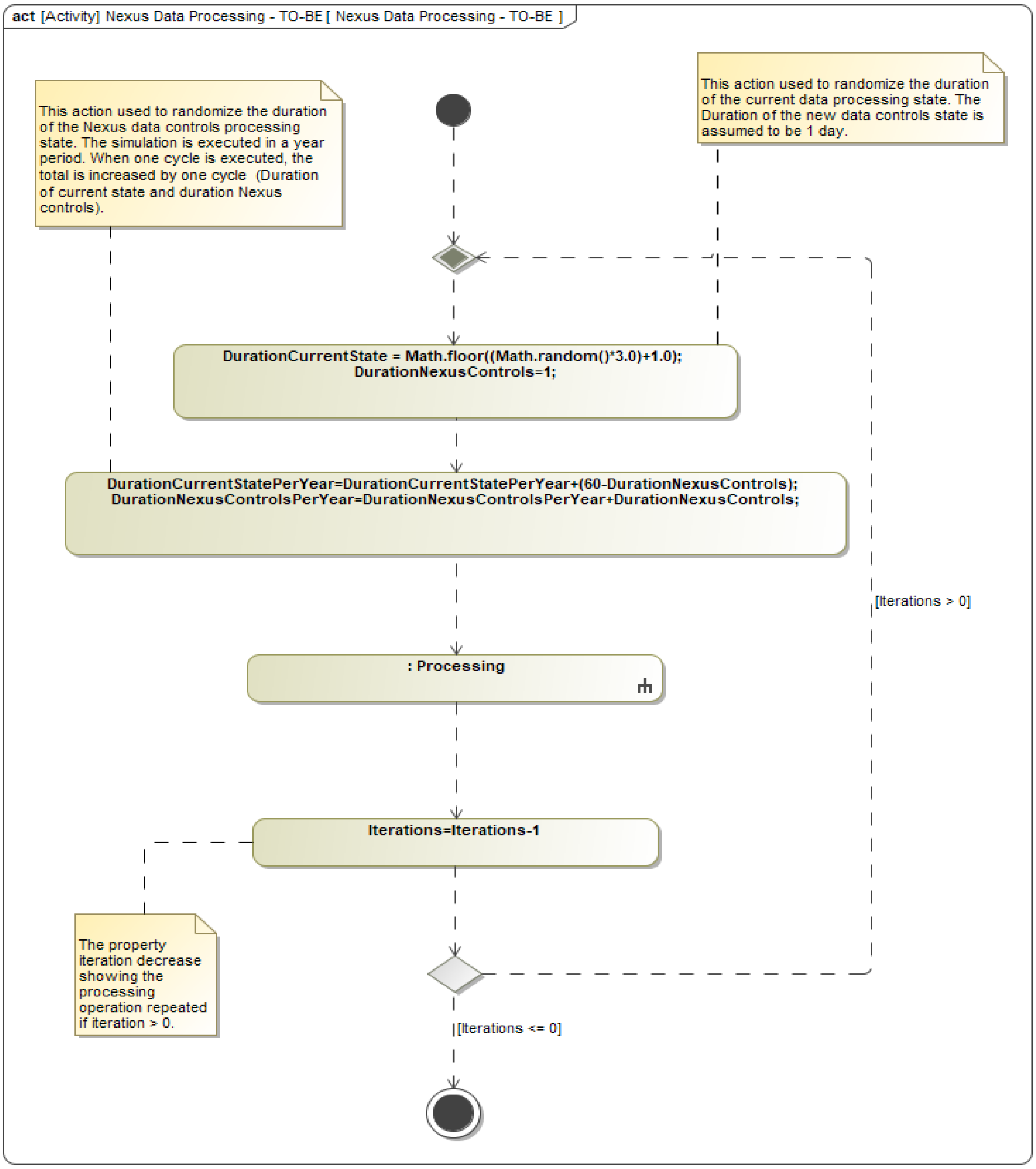

Figure 13. SysML activity diagram showing properties iteration based on the current data processing.

The results show that the model works and is able to process the proposed integrated Nexus data, and to process more than 1 million variables per year and could reject (quality controls) less than 0.005 million variables per year. The results demonstrate the Nexus data optimization simulation is satisfactory. The results show improved data processing based on the Nexus approach, which has improved the process by about 67% (500 data plus per time).

4.4. Triple Nexus Framework Design

For the design of the Triple Nexus Framework, while a structural model captures the system's hierarchy and relationships between internal elements, it can only model the flow of data inputs and outputs through a sequence of actions, which implies modeling behavior. To do this, this work uses the SysML Activity Diagram for modelling since an Activity Diagram in SysML can capture the data flows of water, energy, and housing and represent a set of actions describing the execution of the required actions and the processing of data up to the creation and operationalization of a unified Platform. Figure 14 shows the Activity Diagram of the proposed Nexus Framework behavior model, which captures the data flow from within the water, energy, and housing sectors. It also shows the explicit assignment of behavioral partitions, representing the parties responsible for executing treatment and management activities. Data is obtained from needs assessments, then transformed into composite data, quality-controlled data carried out by Nexus-Experts in compliance with existing protocols and stakeholder validated requirements. Sector data is analyzed and transformed into meaningful data, either sector-specific or composite in the form of nomenclatures during the detailed design phase. Finally, the selected composite and other sectoral data are transformed into meaningful processed data for use by Nexus-Experts when reconfiguring the Nexus Integrated Platform and Database. As the Nexus Framework behavior model captures the main common actions within the Nexus realization process, it can be reused for other specific design scenarios.

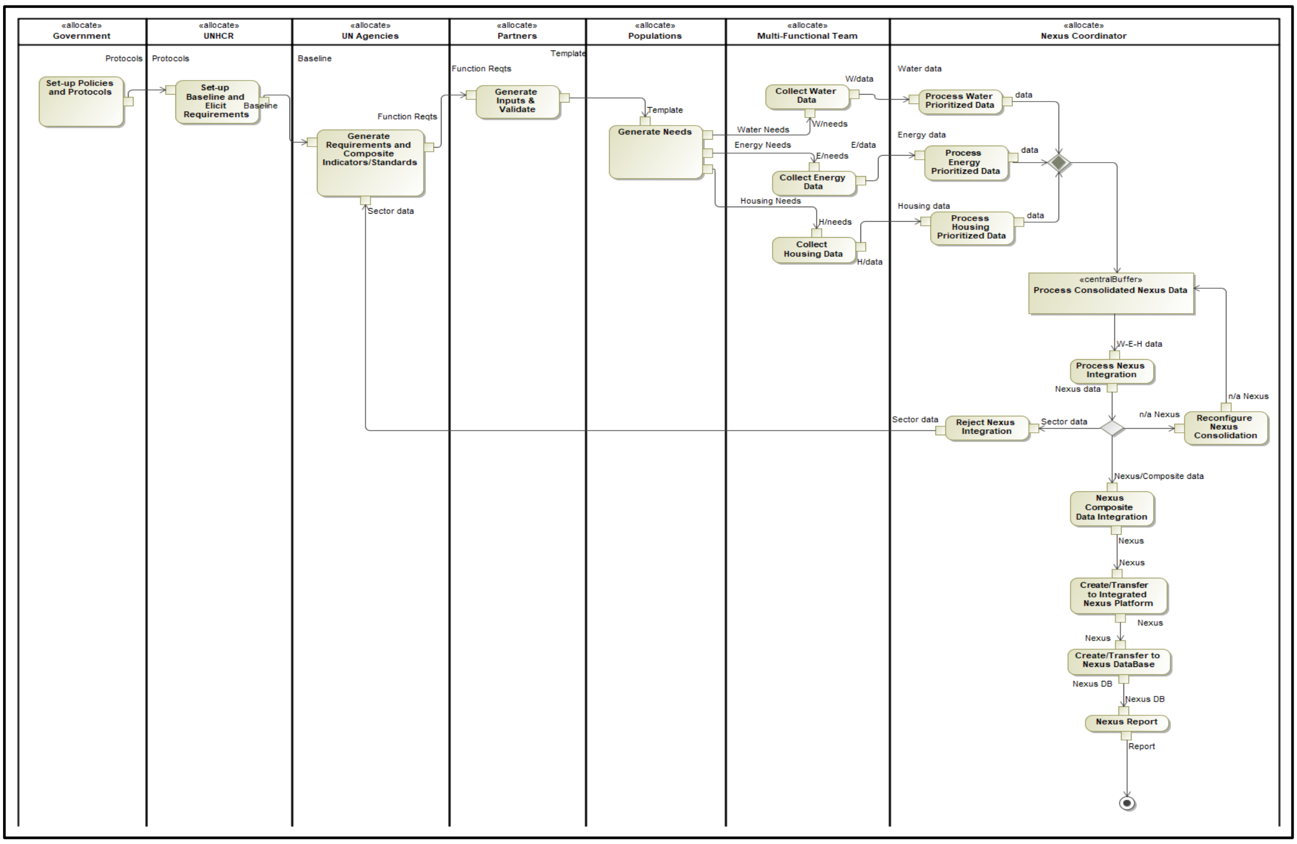

Figure 14. SysML activity diagram for nexus framework behavior model.

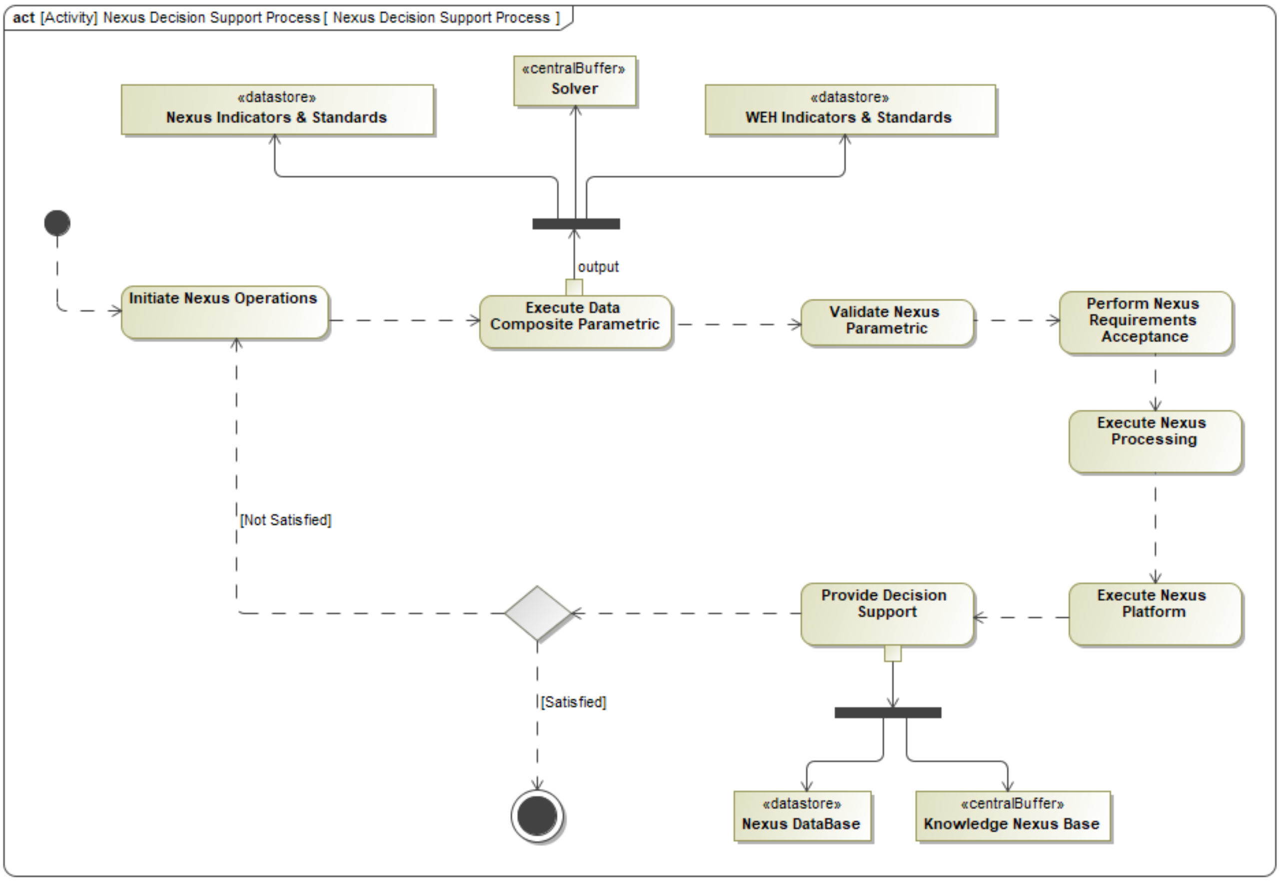

Figure 15. Activity diagram for nexus decision support process.

In addition to the Nexus Framework behavior model, a decision support behavior model is designed to capture how decisions are made. As shown in **Figure 15**, the starting point is to trigger and initiate the required operations of the Nexus Framework behavior model. On the technical side, a parametric model is run with databases and a solver. The solver takes over the execution of the parametric model. To enforce the operating logic of the Nexus Framework, a requirements review is performed to assess whether the requirements are satisfied. If not, advice on implementing variety in the process reconfiguration is provided based on any changes and modifications and a simulation model. After several iterations, the decision support process stops when the objectives of Nexus data processing are in line with requirements and standards, and platform operation is achieved thanks to the trade-off analysis.

5. Conclusion

Through this work, an analysis is conducted to identify significant shortcomings in the current approaches to operational data management, and highlighted the significant benefits that model-based systems engineering (MBSE) methodology could bring in. This resulted in the application of MBSE methods and Systems Engineering (SE) solutions to develop a Triple Nexus Framework, to enable a systematic and integrated view of the system. Concretely, the Triple Nexus Framework is derived from a humanitarian settlement focusing on the triple nexus data processing and capability integration perspectives. The literature review on the Nexus approach that could be deployed there revealed that many studies, approaches, and initiatives in this direction have shown shortcomings and sometimes contrasting viewpoints and have lacked an effectively integrative vision. Building a new framework for integrating the Triple Nexus water, energy, and housing as a generalizable framework base for efficiently application of interrelated data across sectors, is a gateway to building and highlighting the importance of the creation of composite indicators in prioritizing more integrated, optimal, multi-sectoral, and sustainable planning and management of humanitarian settlements.

6. Implications

This paper proposes a framework model for sectoral data processing, integrating water, energy and housing data into a unified platform that serves as a gateway for formulating composite and multi-sectoral indicators widely demanded in today's humanitarian and development operations. The new framework is seen as a significant improvement on humanitarian's current practices and methods and will generate substantial savings in terms of financial, human and time resources. However, future work related to this work could be classified according to the importance in extending the understanding system model in humanitarian operations. Firstly, it is obvious that such a model-driven process using specific MBSE methods should not be too academic. To make it more practical, understandable, and readily digestible for broader practitioners and other decision-makers, future work would involve integrating MBSE-SysML with other tools more "accessible" or "free" applications to perform co-simulation and further analysis and validation of the framework. It's worth noting that SysML has its limitations, and that co-simulation would enable complex dynamic systems to be modeled using other advanced engineering analysis tools. Therefore, in the application of the proposed Nexus framework to the processing and management of Nexus operational data, improvements in functionality for specific tasks will be identified. Their impact on overall system performance will help measure the success of the framework's implementation. With regard to the extensibility of the framework, and to facilitate its application to other systems or operational areas, it is anticipated that it will be adapted to other easily accessible and usable applications, such as MATLAB, Excel, etc. Further work will be carried out to establish linkages between the system's Integrated Data Platform and other existing databases, and to build specific standard operating procedures to reinforce current systems and internal capacities.

On the operational side, technical activities include requirements engineering, capacity analysis, and data orchestration to transform the Triple Nexus Framework into a system based on context and operational data useful for planning and advocacy. In this respect, it is recommended to organize application trials of the Framework in a few existing humanitarian settings responding to the three situations: emergency phase, transitional phase, and stability phase. In addition, a cost-benefit analysis would need to be carried out in comparison with the costs of parallel implementation of sectoral water, energy, and housing programming over the medium and long term. Finally, adoption of the proposed Nexus framework depends largely on a strategic decision and strong commitment from stakeholders and decision-makers in both humanitarian and development operations.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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