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FROM THEORY TO APPLICATION: A PYTHON-DRIVEN IMPLEMENTATION OF THE SEESIM MULTI-CRITERIA DECISION MODEL FOR SUSTAINABLE PUBLIC INVESTMENTS

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ABSTRACT

The efficient allocation of public investments is a cornerstone of sustainable economic and social development. In the face of contemporary challenges, such as climate change, resource management, and social equity, decision-makers require innovative tools to ensure investments yield long-term value. This study presents an enhanced approach to the **Sustainable Economic, Environmental, and Social Investment Model (SEESIM)**, a multi-criteria framework for evaluating public projects. SEESIM leverages the **Analytic Hierarchy Process (AHP)** to integrate environmental, economic, and social dimensions, balancing efficiency with sustainability across diverse regional contexts.

As part of this research, the SEESIM framework has been transformed into a software application developed in **Python**, utilizing the *Python AhpAnpLib Library*. This tool automates the evaluation process, from criteria weighting to project ranking, ensuring transparency, replicability, and ease of use. The resulting software enables policymakers and practitioners to simulate scenarios, monitor project impacts, and optimize resource allocation with precision.

A case study demonstrates the application of the software, showcasing its ability to enhance decision-making and adapt to varying regional priorities. By embedding analytical rigor and technological innovation, this advancement empowers stakeholders to drive sustainable investments that align with long-term strategic objectives. The integration of SEESIM into a practical software solution marks a significant step forward in the pursuit of sustainable development, offering a robust platform for the analysis and optimization of public resources.

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1. Introduction

Sustainable development has become a cornerstone in shaping public policies in Italy and across Europe. In the face of global challenges such as climate change, resource depletion, and social inequality, the urgency to adopt strategies that ensure environmental, economic, and social sustainability has never been more pressing. (Cerniglia et al., 2023) This is particularly evident in the realm of public investments, where decisions have far-reaching implications for the welfare of current and future generations. (Heijdra and Meijdam, 2002), (Cepparullo et al., 2024).

The **Sustainable Economic, Environmental, and Social Investment Model (SEESIM)**, developed to address these challenges, represents an innovative approach to evaluating public investments. Based on the **Analytic Hierarchy Process (AHP) (**Saaty, 1979), the model integrates environmental, economic, and social criteria to guide investment choices in a balanced and effective manner. However, to ensure practical applicability, it is essential to move beyond the theoretical framework and translate the model into an operational tool.

In this research, the SEESIM model has been implemented using **Python**, leveraging the *AhpaApLib* to develop software capable of automating the evaluation process. This software enables the weighting of criteria, the generation of comparison matrices, and the calculation of priorities in a transparent and replicable manner. The goal is to provide policymakers and stakeholders with a practical tool to simulate scenarios, monitor impacts, and optimize resource allocation.

The Python implementation not only enhances decision-making efficiency but also makes the SEESIM model adaptable to a variety of regional contexts, respecting the complexity and diversity of local priorities. A case study demonstrates how the software can guide investment decisions, highlighting its positive impact in terms of environmental sustainability, economic resilience, and social acceptability.

This work aims to fill a critical gap in the literature and practice by offering a concrete tool to promote sustainable development through targeted public investments. The combined approach of analytical rigor and technological innovation positions this research as a benchmark for more sustainable and strategic public policies. (Baffo et al., 2023)

Table 1: Decision-making criteria and respective sub-criteria

#	Criteria	Sub Criteria
1	**C1.** **Efficiency (EF)** *Evaluates the project's ability to be realized within predetermined timelines and budgets, maintaining high quality standards and effective resource management.*	**SC1.1 Timelines:** Meeting project deadlines
		SC1.2 Budget: Completion within the forecasted cost limits
		SC1.3 Quality: Excellence level in project completion
		SC1.4 Resource: Optimization of available resources usage
2	**C2.** **Economic Impact (EI)** *Measures the project's contribution to the local economy through job creation, GDP increase, attraction of private investments, and support for industrial development*	**SC2.1 Job Creation:** Generation of new employment opportunities
		SC.2.2 Increase GDP: Enhancement of economic value in the region
		SC2.3 Private Investments: Stimulation of non-governmental capitals

		SC2.4 Local Industrial Sector: Growth and strengthening of regional industries
3	**C3. Social Benefits (SB)** *Examines the project's effects on society, including improved access to services, enhanced quality of life, reduced disparities, and empowerment of local skills*	**SC3.1 Access to Services:** Easier access to essential services.
		SC3.2 Quality of Life: Enhancements in overall well-being.
		SC3.3 Social Disparities: Decrease in inequalities among social groups.
		SC3.4 Local Skills: Enhancement of local abilities and knowledge.
4	**C4. Sustainability (SS)** *Assesses the project's commitment to minimizing negative environmental impacts, promoting sustainable practices such as emissions reduction, conservation of natural resources, and waste management*	**SC4.1 CO_2 Emissions**: Decrease in carbon footprint
		SC4.2 Natural Resources: Protection of resources like water and soil
		SC4.3 Biodiversity: Rise in the variety of living species
		SC4.4 Waste Management: Reduction, recycling, and reuse of waste
5	**C5. Innovation and Technology (IT)** Considers the project's contribution to technological innovation, evaluating the adoption of new technologies, improvement of IT infrastructure, development of innovative solutions, and collaboration with research entities	**SC5.1 New Technologies:** Introduction of advanced technological solutions
		SC5.2 IT Infrastructure: Development of technological architecture
		SC5.3 Innovative Solutions: Creation of new methods or products
		SC5.4 Research Institutions: Synergies with research entities for innovation

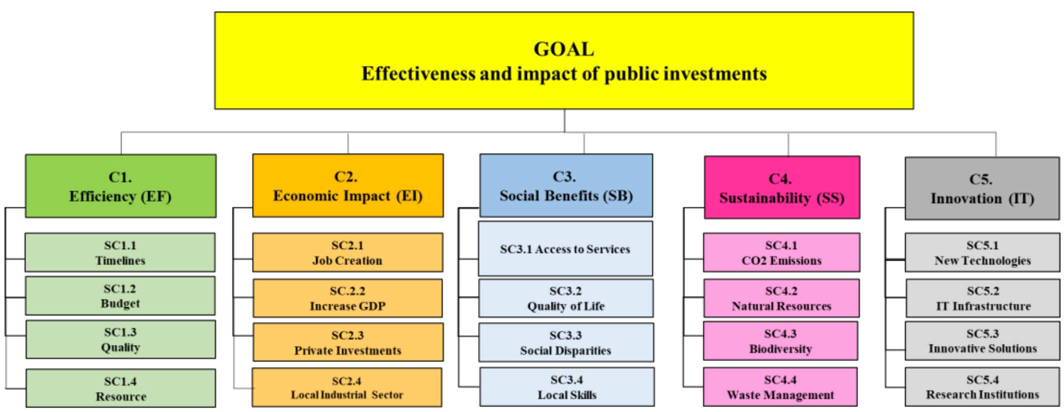

Figure 1: AHP Decision Model (Author's elaboration)

2. Literature Review

This study builds on a foundation of significant prior work addressing sustainable public investments and decision-making frameworks. Notably, Saaty's seminal work on the **Analytic Hierarchy Process (AHP)** (Saaty, 1979) provides the methodological cornerstone for this research, offering a structured and replicable approach to multi-criteria decision-making. Additionally, Baffo et al. (2023) emphasize the importance of balancing immediate economic needs with long-term sustainability goals in public investments, highlighting the complexity of integrating environmental, economic, and social dimensions. (Cucchiella et al. 2023) explore the challenges of adapting sustainability evaluation models to diverse regional contexts, demonstrating the necessity for flexible frameworks. Furthermore, (Cerniglia et al. 2023) address the urgency of aligning public investment strategies with sustainability targets, particularly in the European context shaped by the Green Deal and National Recovery and Resilience Plans. Finally, (Lbahar et al. (2022) illustrate the potential of advanced decision-making tools in optimizing resource allocation, underscoring the gap in practical, software-based implementations of such frameworks. Despite these advances, the literature often falls short in offering operational tools that policymakers can directly use to implement sustainability-oriented investment strategies. This study addresses this gap by translating the SEESIM model into a Python-based software solution, bridging the divide between theoretical frameworks and practical application. By automating the evaluation process and ensuring adaptability across regional contexts, this research contributes a significant tool to support informed and strategic public investment decisions, ultimately advancing the pursuit of sustainable development.

3. Hypotheses/Objectives

This study focuses on the development and implementation of a comprehensive decision-making model tailored to optimize sustainable public investments. The specific objectives and hypotheses of this research are as follows:

1. **Develop a decision model**: To design and refine the **Sustainable Economic, Environmental, and Social Investment Model (SEESIM)**, which integrates environmental, economic, and social dimensions using the **Analytic Hierarchy Process (AHP)**.
2. **Implement the model in Python**: To translate the SEESIM framework into a functional Python-based software tool using the *AhpaApLib*, ensuring transparency, replicability, and ease of use for decision-makers.
3. **Adapt to regional contexts**: To ensure that the model is flexible and applicable across diverse regional and socio-economic settings, accommodating varying priorities and constraints.
4. **Contribute to sustainable decision-making**: To provide policymakers and stakeholders with a practical tool to optimize resource allocation while balancing economic, environmental, and social objectives.

Hypotheses:

- The SEESIM model, when implemented in Python, will enhance the efficiency and accuracy of the decision-making process for sustainable public investments.
- Integrating automated tools (e.g., Python-based software) with AHP methodologies will significantly improve the transparency and replicability of multi-criteria decision-making.
- The SEESIM tool will demonstrate adaptability to diverse regional contexts, ensuring its relevance for varying socio-economic and environmental scenarios.
- Policymakers using the Python-based SEESIM software will achieve better alignment of public investments with long-term sustainability goals compared to traditional evaluation methods.

By addressing these objectives and testing these hypotheses, this study aims to bridge the gap between theoretical decision-making frameworks and their practical application in public investment strategies.

4. Research Design/Methodology

The development of the SEESIM model was guided by a combination of literature review and expert input. The goal, criteria, sub-criteria, and alternatives were identified through an in-depth analysis of previous studies on sustainable public investments and multi-criteria decision-making frameworks, ensuring alignment with established sustainability objectives. Expert opinions were gathered from a panel of six professionals, including engineers, economists, and AHP specialists, who provided pairwise comparisons to prioritize the criteria and sub-criteria.

5. Results/Model Analysis

The SEESIM model has been successfully implemented in Python using the *AhpaApLib* to automate the analytical steps of the Analytic Hierarchy Process (AHP). This implementation serves as the foundation for a dynamic decision-support tool designed to prioritize sustainable public investments.

Hierarchy Structure

The model is organized into a clear hierarchy:
Goal: Optimize sustainable public investments.
Main Criteria: Efficiency, Economic Impact, Social Benefits, Sustainability, and Innovation & Technology.
Sub-Criteria: Each main criterion is divided into four sub-criteria. For example:
Efficiency: Timelines, Budget, Quality, and Resource Optimization.
Sustainability: CO_2 Emission Reduction, Resource Conservation, Biodiversity, and Waste Management.

Judgment Matrix in Python
The judgment matrix for the main criteria, developed based on expert evaluations, has been coded in Python. Below is an example of pairwise comparisons:

Table 2: Example Matrix

Criteria	Efficiency	Economic Impact	Social Benefits	Sustainability	Innovation & Technology
Efficiency	1	3	5	7	9
Economic Impact	1/3	1	3	5	7
Social Benefits	1/5	1/3	1	3	5
Sustainability	1/7	1/5	1/3	1	3
Innovation & Technology	1/9	1/7	1/5	1/3	1

The matrix is designed to allow for modifications and recalculations, ensuring flexibility in different decision-making scenarios. Additionally, the Python script automatically generates an Excel file where pairwise comparison values can be easily entered, simplifying data collection and updates for users.

Consistency Check

While the final consistency indices have not yet been calculated, the Python implementation enables automatic validation using the **Consistency Ratio (CR)**. This ensures that matrices with CR > 0.10 can be promptly adjusted to improve reliability.

Next Steps

The next phases of the study include:

1. Generating weights for criteria and sub-criteria based on expert input.
2. Visualizing results through bar charts and radar charts to effectively communicate priorities.
3. Conducting sensitivity analysis to test the robustness of the model under various judgment scenarios.

This implementation represents an important foundation for a transparent, flexible, and adaptable decision-making process aligned with sustainability objectives. The addition of the Excel file further enhances the model's accessibility, enabling stakeholders to easily contribute to the decision-making process.

6. Conclusions

This study represents a significant step in advancing decision-making processes for sustainable public investments by developing the SEESIM model and implementing it in Python. The practical contribution lies in transforming a theoretical AHP framework into an operational software tool. This implementation enhances the efficiency, transparency, and adaptability of the decision-making process, enabling policymakers to prioritize projects that align with sustainability objectives.

From a theoretical perspective, this study reinforces the utility of AHP in structuring complex decisions and highlights the benefits of integrating computational tools into traditional models. The Python-based implementation makes SEESIM accessible and scalable for varying regional and socio-economic contexts.

Future studies should focus on validating the model with real-world data and applying it to diverse investment scenarios. Incorporating advanced features such as machine learning algorithms for predictive analysis or interactive dashboards for stakeholder engagement would further enhance the tool’s utility.

This contribution differs from current scholarship by bridging the gap between theory and practice, offering not only a robust framework but also a functional tool that facilitates actionable insights.

7. Limitations

While the SEESIM model provides a promising framework for sustainable public investment decision-making, certain limitations should be acknowledged:

1. **Preliminary Nature**: The current implementation has focused on coding the hierarchical structure and judgment matrices, but final calculations and real-world validation are pending.
2. **Data Dependency**: The accuracy of the model depends heavily on expert judgments and data availability, which may vary across regions and projects.
3. **Static Judgments**: The AHP method relies on fixed pairwise comparisons, which may not fully capture the dynamic and evolving nature of sustainability priorities.
4. **Limited Features**: The initial Python implementation lacks advanced functionalities, such as automated sensitivity analysis or integration with real-time data.

To address these limitations, future iterations of the study should include larger datasets, a more diverse pool of experts, and iterative validation using real-world projects. Enhanced software features, such as interactive dashboards and integration with external databases, could significantly improve the model's usability and scalability.

By reflecting on these limitations, this research provides a foundation for further exploration and refinement, guiding colleagues interested in advancing decision-making frameworks for sustainable public investments

8. Key References

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9. Appendices

Modello AHP

```
# from AhpAnpLib import *
from AhpAnpLib import inputs_AHPLib as input
from AhpAnpLib import structs_AHPLib as str
from AhpAnpLib import calcs_AHPLib as calc

#create the model
EvaluationProject=str.Model("Modello SEESIM")
```

```
#create all nodes
goal_node=str.Node("GoalNode",0)
efficiency=str.Node("C1 Efficiency (EF)",1)
economic_impact=str.Node("C2 Economic Impact (EI)", 2)
social_benefit=str.Node("C3 Social Benefits (SB)", 3)
sustainability=str.Node("C4 Sustainability (SS)",4)
innovation_t=str.Node("C5 Innovation and Technology (IT)",5)

#create node Sub Criteria
sub11=str.Node("SC1.1 Timelines",6)
sub12=str.Node("SC1.2 Budget",7)
sub13=str.Node("SC1.3 Quality",8)
sub14=str.Node("SC1.4 Resource",9)
…
#Alternative
alt1=str.Node("Project A",90)
alt2=str.Node("Project B",91)
alt3=str.Node("Project C",92)
#cluster
cluster0 = str.Cluster("GoalNode", 0)
cluster1 = str.Cluster("Criteri", 1)
cluster2 = str.Cluster("Subcriteri1", 2)
…
#addNodeCluster
cluster0.addNode2Cluster(goal_node)
cluster1.addMultipleNodes2Cluster(efficiency, economic_impact,…)
cluster2.addMultipleNodes2Cluster(sub11,sub12, sub13,sub14)
…
#Add clusters to model
EvaluationProject.addMultipleClusters2Model(cluster0, cluster1, cluster2, cluster3, cluster4,
cluster5, cluster6, cluster22)

#Nodi ai criteri
EvaluationProject.addNodeConnectionFromNodeToAllNodesOfCluster("GoalNode","Criteri")
EvaluationProject.addNodeConnectionFromNodeToAllNodesOfCluster("C1Efficiency(EF)",
"Subcriteri1")
…
# Add connections from each sub-criteria to all nodes in the "Alternative" cluster
EvaluationProject.addNodeConnectionFromNodeToAllNodesOfCluster("SC1.1Timelines", Alte")
EvaluationProject.addNodeConnectionFromNodeToAllNodesOfCluster("SC1.2Budget", "Alte")
…
#show nodes and connections to help us to check connections
#EvaluationProject.drawGraphNodes()
#export Excel questionnaire
#the third parameter we set as True so the estimated results will be included in the exported Excel
questionnaire
input.export4ExcelQuestFull(EvaluationProject,"EvaluationProject_Excel_empty.xlsx",True)
#set up the file path and name of the filledin Excel questionnaires and the final results Excel file
inputFile="EvaluationProject_Excel_filledIn.xlsx"
outputFile = "EvaluationProject_Excel_Results.xlsx"

#calculate results and export the results to the outputFile.
#we set the fourth parameter as True, so the inpuFile will be used in calculating
```