Computational aspects of sustainability: Conceptual review and analytical framework

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Computational aspects of sustainability: Conceptual review and analytical framework

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Abstract

The main purpose of the present study is to feature the computational practice of green policy performance measurement. Computing the progress of the green economy includes topics as indicators and measures to characterize environmental sustainability, methodological issues to indicate and present spatiotemporal patterns of resource use and pollution, computational frameworks for comparisons of environmental management among economies / economic sectors / socio-economic systems, computational techniques to define the structure, dynamics, and change in ecosystems. Results are discussed in support of green policies.

Keywords: Computational Economics; Sustainability.

1. Introductory overview

The applied theoretical and analytical contributions guide policy-makers and government officials in designing new policy scenarios for the investigation of sustainability and the appropriate advanced and updated methods to be used. The empirical contributions provide evidence to support and inform current policy debates. Collected here are some empirical and theoretical developments for the development and application of environmental models.

This study is intended to provide researchers with sufficient background to investigate the multiple dimensions of sustainable development and to introduce common or innovative tools and approaches to analyze and understand them with the audience assumed to have some basic knowledge of environmental modeling and computational integration of analytical techniques.

2. Main characteristics of the existing and current research on sustainable development

Sustainable development is a multidimensional concept. The interconnectedness between segments of the entire system called sustainable development is undoubted. In the last five years, there is significant research interest in computational tackling of the various environmental problems and environmental policy implications.

Research activity on green policy performance measurement is present in several disciplines such as computer science, finance, economics, financial engineering, physics, engineering, social sciences, environmental science, energy, business, management and accounting, mathematics, decision sciences. Relevant documents were identified from selected research databases, namely Scopus, Google Scholar, and EBSCOhost, by executing search queries for keywords like,

'computing', 'SDGs', 'sustainability', and 'green policy'. The results are reported in Table 1.

Table 1. Review of the literature on computational tools and methodologies for studying sustainability.

The literature search results		
Scientific publishing knowledge base	**Keywords**	**Search results**
Scopus	computing AND sustainability	3,130 documents
	"sustainable development goals" AND computing	527 documents
	computing AND sustainability AND "green policy"	88 documents
Google Scholar	computing AND sustainability AND "green policy"	511 results
EBSCOhost	computing AND sustainability AND "green policy"	35,724 results (years 2016-2020)
	"sustainable development goals" AND computing	88 results (years 2016-2020)

Understanding sustainable development linkages and achieving the required policy trade-offs across the environmental, economic, and social spheres requires a wide range of tools and methodologies.

Past and current studies develop core theories, frameworks, and features that underpin research in sustainability issues. Coverage areas include:

- Economic growth and the environment: environmental problems eco-friendly policies through computable models
- Computational tools, methods, and approaches for studying the environment in all its dimensions: pollution, the despoliation of resources, air and water quality, noise pollution, biodiversity and valuation, acid rain, deforestation, ozone depletion, polluted seas, global warming, and climate change, population poverty, and economic growth, decoupling of environmental and resource pressures, sustainable

transportation, sustainable tourism, environmental efficiency, and productivity analysis, sustainable development, waste management.

3. A note on special issue "Computational Aspects of Sustainability" in *Computational Economics* journal

The special issue "Computational Aspects of Sustainability" (Halkos and Tsilika, 2021), collected papers with new contributions to this literature with a special focus on manuscripts adopting computable models for green growth, analyzing policy interactions with quantitative methods, performing cost/benefit analysis based on economic-ecological transformations.

This special issue aims to consider the "economic growth and environment" dispute in terms of the most updated and efficient methods applied in various modeling techniques together with the use of better and larger data sets. Above all, the computational tools and methodologies for studying sustainable development in all its dimensions: environment, health, economic impacts (see fig. 1). Specifically:

- causal relationships that exist in the field of Global Warming
- dynamic interactions between the economy, energy, climate change
- predictions of Global Warming Impacts
- trade-offs between environmental and economic performance
- effects of urban planning and transportation policies,
- urban land use, mobility patterns, and their environmental impacts
- quantitative measurement and evaluation of urban competitiveness
- SMEs' supply chain sustainability performance / sustainability performance measurements of SMEs
- pollution and health
- environmental efficiency

Figure 1. Key themes and topics of the special issue "Computational Aspects of Sustainability" published by Computational Economics (Springer)

The papers of the special issue (figure 2) are fully consistent mainly with five sustainable development goals, namely, goal 3: Good Health and Well Being, goal 7: Affordable and Clean Energy, goal 11: Sustainable Cities and Communities, goal 12: Responsible Consumption and Production, goal 13: Climate Action.

Figure 2. Articles of the special issue "Computational Aspects of Sustainability" published by Computational Economics (Springer)

The authors of the selected papers seek and suggest the computational framework to analyze the environmental dimensions of sustainable development. Specifically:

Song, and Xie (2021) measure and compare regional urban competitiveness in the eco-economic context. They establish an evaluation model with the help of the dynamic factor analysis method which aims to quantitatively measure the degree and ranking of the competitiveness of cities. The model is tailored to reflect changes in the competitiveness of cities in terms of time, but also to compare the competitiveness of different cities in the same period. The computational approach uses *STATA* software and appropriate panel data according to the basic ideas of dynamic factor analysis. Huaihe River's eco-economic belt construction is considered by the authors as a typical case study in which the measurement approach of urban competitiveness can be applied and attain policy integration. The paper concludes that understanding the different developmental strengths and comprehensive competitiveness of each city is key to successful regional ecological economy construction.

On the path of "eco-friendly policies through computable models" a new modeling approach can be found in (Tikoudis and Oueslati, 2021) with an urban Computable General Equilibrium model, the Multi-Objective Local Environmental Simulator (MOLES). The model aims to assess the performance of local and national policy instruments that target transportation, energy consumption from mobile sources, and land use in urban areas. It is also designed to capture the synergetic effects of urban planning and transportation policies. The research results provide theoretical reference for the evaluation of the environmental and economic impacts of urban policies using the urban area of Auckland, New Zealand as the sample. The version of MOLES for Auckland is considered by the authors as a laboratory in which

land-use and transportation reforms for similar cities can be examined, yielding policy recommendations with a considerable degree of external validity. The model helps policymakers distinguish potential best practices, i.e. policy interventions that are economically efficient, environmentally effective, and balanced from a fiscal and distributional viewpoint. MOLES is also a platform to detect worst practices.

Indicating and linking the environmental dimensions of sustainable development, Tsadiras et al. (2021) develop a model of the causal relationships that exist in the field of Global Warming. A Semantic Web-based software tool/application called "Web-FCM" is designed and implemented using the well-established Artificial Intelligence technique of Fuzzy Cognitive Maps (FCMs). The model visually simulates the FCM dynamic behavior and studies the equilibrium that the FCM dynamic system reaches. Common frontend and backend web development technologies such as HTML, JavaScript, CSS, and Java Server Pages (JSP) were chosen for the implementation of the proposed Web-FCM system. The most important component of the software is the use of Semantic Web technologies to represent the related entities (concepts, scenarios etc.) and manipulate data. Policymakers can use this technique and tool to make predictions by viewing dynamically the consequences that the system predicts to their imposed scenarios and share them through the World Wide Web. An FCM model that concerns Global Warming demonstrates the capabilities of the proposed Web-FCM system.

A new framework for measuring and managing the supply chain sustainability for small and medium-sized enterprises is proposed by Dey et al. (2021). They have managed to identify empirically the conditions that govern the economic, operational, social, and environmental practices and the performance of the involved SMEs and propose a package of amelioration measures to be examined through benchmarking

against sectoral best practice. The proposed model exploits the advantages of a joint SEM and DEA analysis: SEM and DEA analysis has offered the ability to extract through SEM suitable overall input and output latent constructs of sustainability practices and performances. This approach is more powerful than similar research that used separately DEA and SEM for sustainability analysis. This suggested joint approach was empirically validated in two varied set-ups: Midlands in the United Kingdom and Normandy in France.

The effects of social variables on the environment is a key dimension of sustainable development. Halkos and Argyropoulou (2021) examine the effects of air pollution on health, using the nonparametric approach of DEA, in *MaxDea Pro*. They employed the statistical procedure of bootstrapping, implemented with bootstrapping bias correction. Two DEA models are specified with capital and labor as inputs and GDP/c as desirable and mortality from exposure to $PM_{2.5}$ as undesirable (bad) outputs in the first and environmentally related tax revenue as additional input in the second specification. The main result is the ranking of a set of 18 European countries for the years 2000, 2005, 2010, 2014, 2015, and 2016, according to their assigned efficiency scores. Differences in efficiencies extracted may be due to the different chemical compositions of the particles stemming from different sources of emissions with varying chemical characteristics.

4. Integration of computing in environmental studies and the usage of the supporting software

Green fiscal transfers incorporate ecological performance in the fiscal allocation proceeds. Fiscal transfers redistribute revenue between and within regions and countries according to agreed fiscal allocation agreements. Halkos, Managi and Tsilika (2020) rank countries and geographical regions in the international green bond

transfer network, given the interconnectedness of institutions involved. Weighted network analysis in Wolfram *Mathematica* (v. 11.3) and in *Mathematica* interface for igraph package, IGraph/M (v. 0.4) revealed the influence of regions and countries in terms of their green bonds' exports and imports volume and frequency. The systemic importance of financial infrastructures is quantified and then, comparisons among different regions and countries were achieved. The empirical data used in the analysis include regions and their geographical targets in the green bond transfer network as illustrated in figure 3. Green bond flows appear in figure 4. Figure 5 illustrates the allocation of project categories in the green bond transfer network under study.

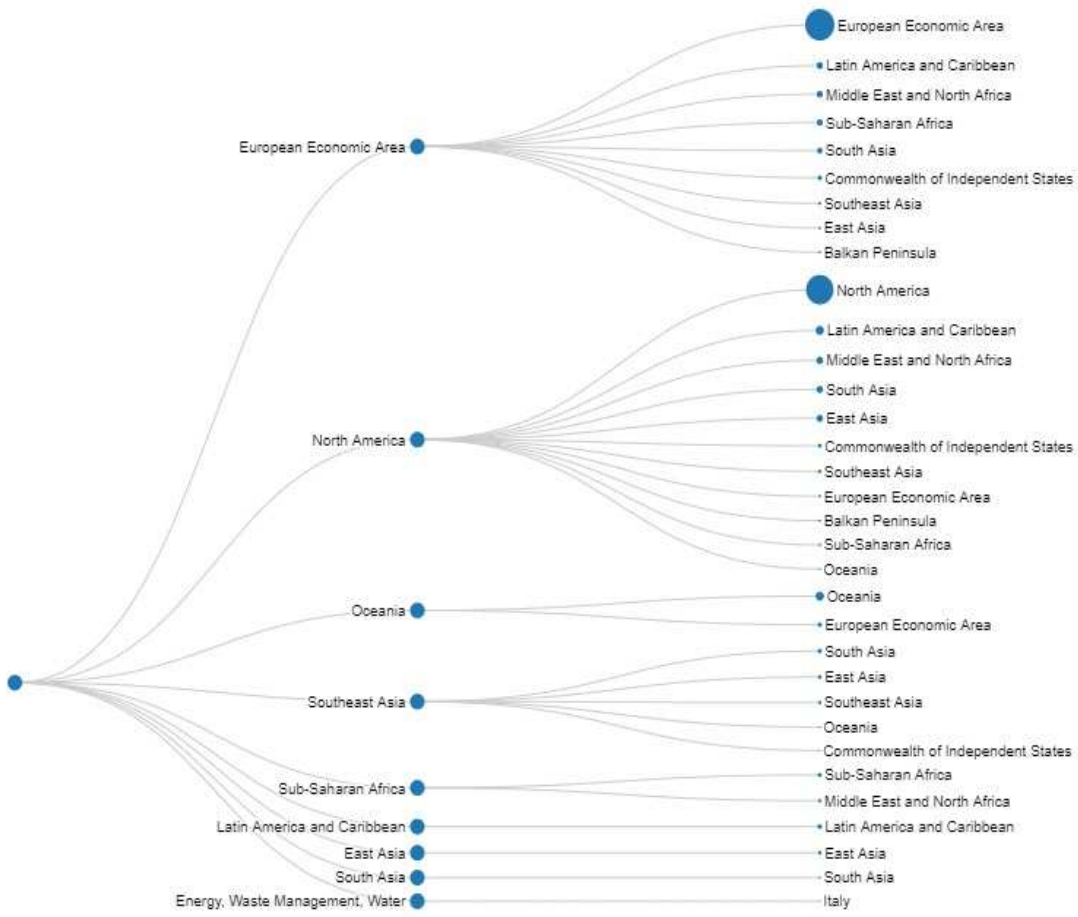


Figure 3. Regions' extroversion in green investments. Region-to-region investing connections.

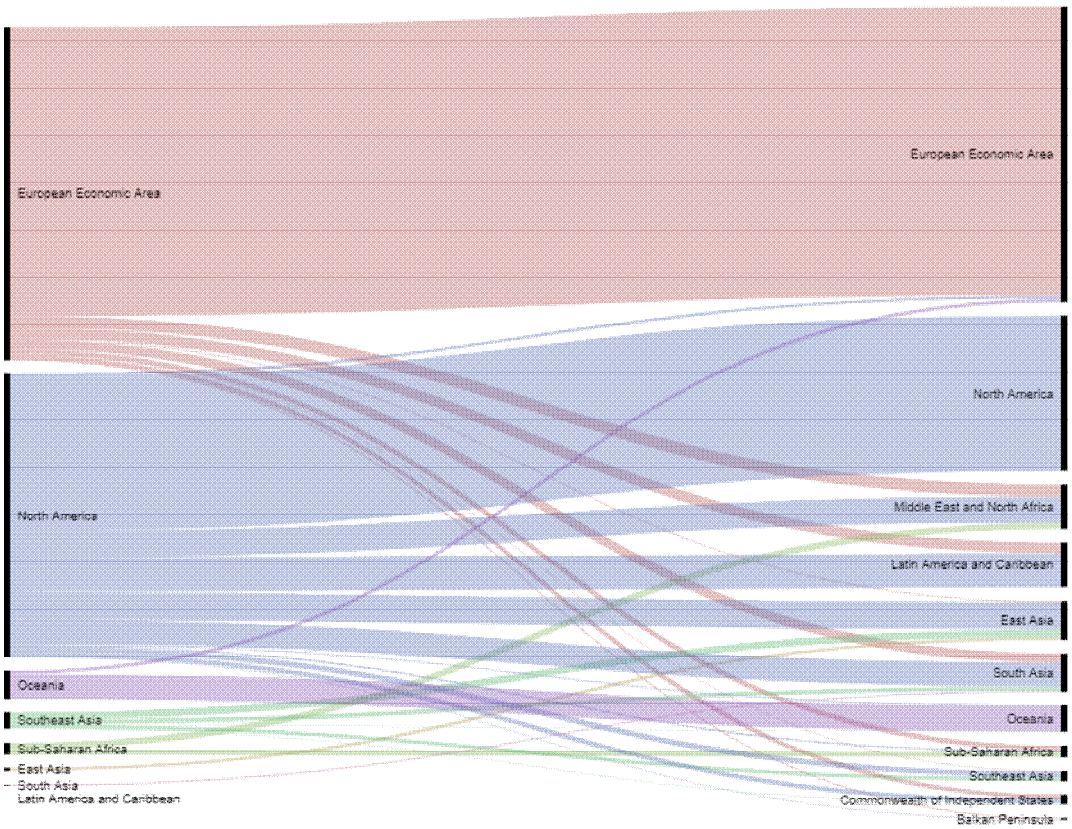


Figure 4. Global proceeds flows from allocator regions to project regions. Region-level distribution of GB proceeds allocations (constant 2010 USD)

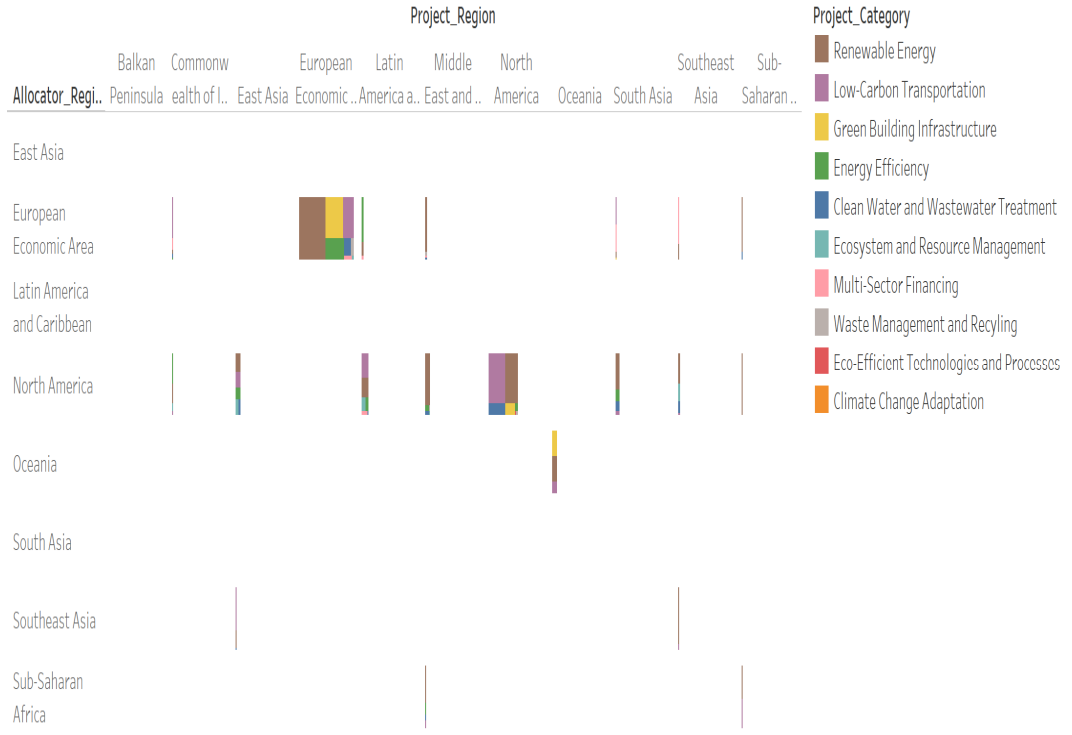


Figure 5. Region-to-region investing connections with reference to project category

Halkos and Tsilika (2019a, b), Halkos Managi and Tsilika (2018) and Halkos et al. (2018) provide practical guidance to decision-makers to address the Sustainable Development Goals (SDGs) 11 and 13, namely SDG 11 "Organize Climate Action" and SDG 13 "Sustainable Cities and Communities", proposing computational tools, methods, and approaches. Each computational approach develops a narrative perspective of the situation in relation to the environmental dimensions of SDGs in general, and to SDGs 11 and 13 in particular, based on an understanding and analysis of current and historic trends. In (Halkos and Tsilika, 2019a) the tools are presented with all information a user could need, with the tool name, a brief description, the developer, use requirements (such as open-source, licensing, or technical requirements) (figure 6).

Figure 6. Software applicable to a visual analytics approach to environmental responsibility and policy

Halkos and Tsilika (2016) consider dynamic multisectoral economy models consisting of linear IO balance equations. The models under study are based on input-output analysis, which is a useful tool in studying the relations between economy, technology, and environment[1]. A static input-output model is sufficient to determine the impacts of new technologies on the economy and the environment. Contrary to static input-output models, dynamic input-output models include both the effects of various economic and ecological factors and their changes over time. Halkos and Tsilika (2016) use functional programming in symbolic programming languages (figures 7,8) to check the appropriate stability conditions and, if it is feasible, to approach asymptotically a steady state of a system. The result is to determine how a situation in a system might turn out over time.

```
charvalues[poly_, var_] := Table[Abs[Root[poly, i]], {i, 1, Length[Solve[poly == 0, var]], 1}]

stabilitytest[poly_, var_] := If[Max[Table[Abs[Root[poly, i]], {i, 1, Length[Solve[poly == 0, var]], 1}]] < 1, stable, unstable]

steadystate[a_, initial_] := Simplify[JordanDecomposition[a][[1]].Limit[MatrixPower[JordanDecomposition[a][[2]], k], k → ∞].Inverse[JordanDecomposition[a][[1]]].initial // MatrixForm

distributionk[a_, initial_] := Simplify[JordanDecomposition[a][[1]].MatrixPower[JordanDecomposition[a][[2]], k].Inverse[JordanDecomposition[a][[1]]].initial // MatrixForm
```

Figure 7. Computer codes in *Mathematica* for dynamic IO models

[1] Such analysis may accompany or extend research related to problems of transboundary nature (Halkos, 1992, 2013).

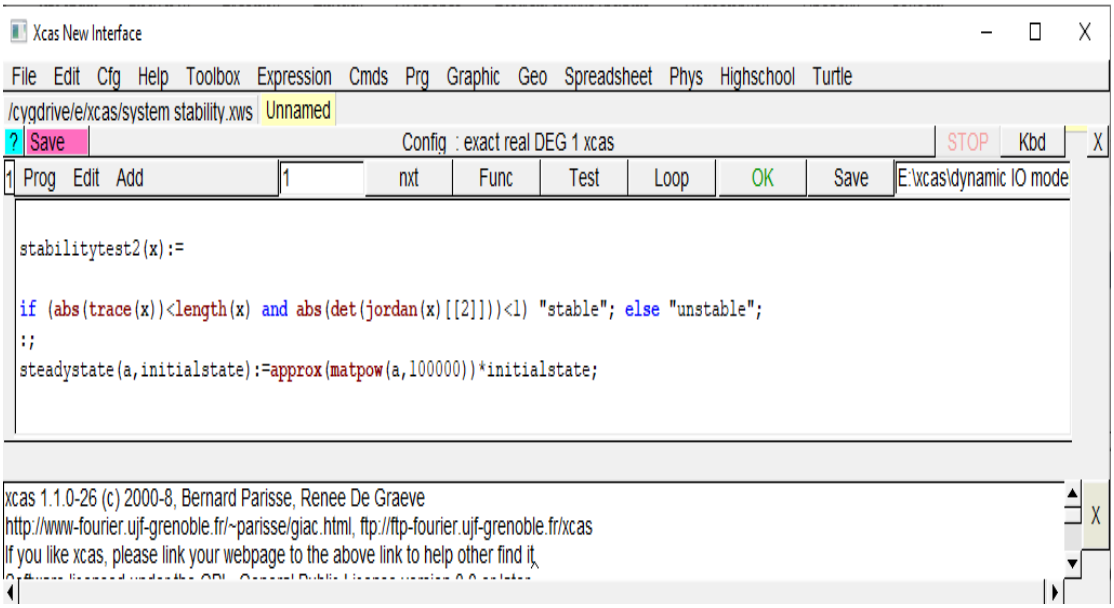


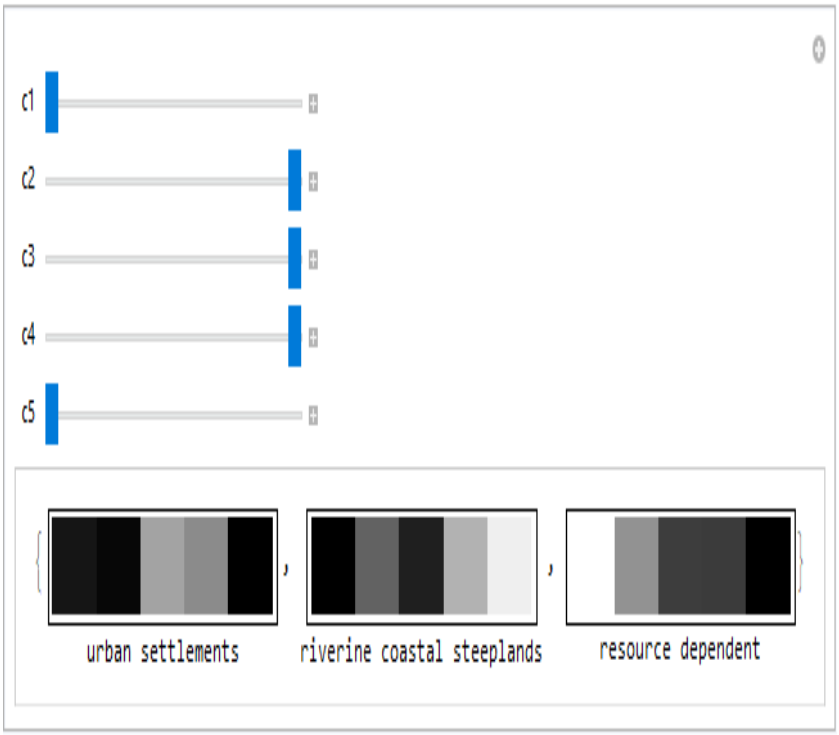
Figure 8. Program in Xcas for dynamic IO models

Halkos and Tsilika (2014) propose dynamic interfaces to obtain either the synthesis or the numerical estimate of cost distribution variable vector for costs related to the synergistic environmental effects. Considering the primary costs caused by climate-related factors, the synergistic impact mechanism among certain climate-related factors allows for a similar synergistic impact mechanism of the corresponding primary costs. With notations and operations of matrix algebra, using either a technical coefficient or a functional matrix to illustrate climate-related cost interactions and synergistic effects, a regional model that forecasts the cost distribution which the primary synergistic mechanism causes from the principal costs of certain climate-related factors is formulated.

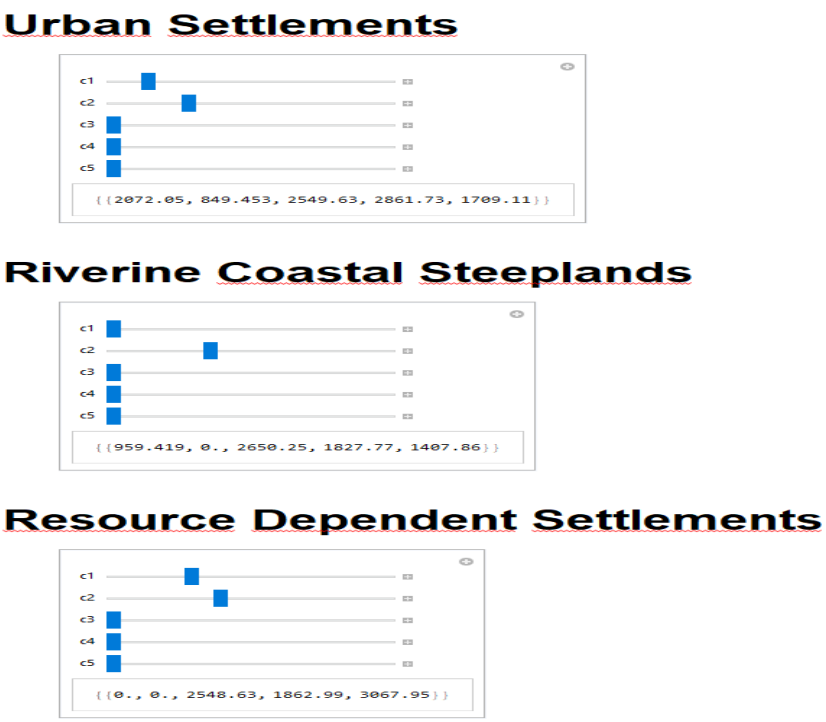
The creation of dynamic interfaces in *Mathematica* allows for varying parameters for the existence of costs, the amount of costs and the impact indicators of costs (see indicatively figure 9). The direct cost distribution of climate-related factors is defined in the row matrix $(c_1 \quad c_2 \quad c_3 \quad c_4 \quad c_5)$. In *Mathematica*'s computing environment, the product of the matrix of direct costs with the matrix of synergistic cost effects is depicted in a discrete array of squares (figure 9a) or it is evaluated

numerically (figure 9b). In another version of the comparative output, the number of costs per settlement and per industry is counted and listed.

Halkos and Tsilika (2017) cope with the environmental dimensions of sustainable development. They study the synergistic impact mechanism of climate-related factors by utilizing graph models (figure 10). Specifically, the interactions between migration, phenomena of flooding-landslides-fire, air and water pollution, human health, and energy-water-other resources are modeled in a causal network. Graph construction, visualization, and graph measurements are performed in *Mathematica*. The analysis highlights the critical climate-related factors in three types of settlements. Criticality is decided when nodes (factors) appear high centrality indicators. This approach provides information on risk mapping, early warning, risk awareness in a given ecosystem and sets the directions for climate change control policies.



(a)Visual representation of costs



(b)Numerical evaluation of costs

Figure 9. Dynamic interfaces in *Mathematica* for the estimation of climate-related costs

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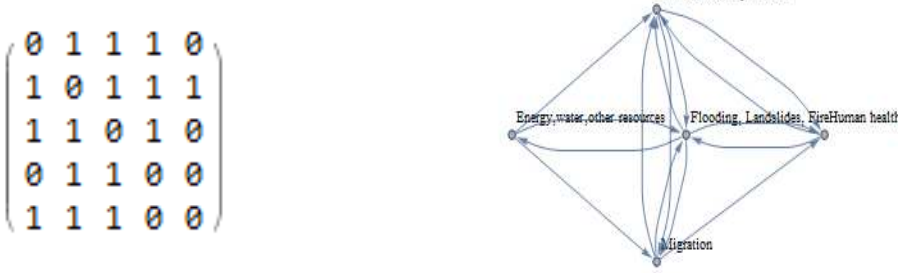

(a) Adjacency matrix associated with the problem (b) Graph model associated with the problem

Figure 10. Causal network of the synergistic impact mechanism among certain climate-related factors.

Sustainability, in terms of corporate social responsibility reports, is evaluated by Halkos, Nomikos & Tsilika (2021). The paper aims to help policymakers understand the linkage of corporate social responsibility with environment-related goals and economic activity. The results are data-driven, coming from a panel dataset from publicly reported economic and environmental country data aggregated over 6 continents (aggregation process: summation) covering the period from 1999 to 2017.

5. Goals and Desired Outcomes

The adoption of an integrated approach (from modeling and integration of computational techniques to monitoring and review) is a key component to quantify the impact of climate change on the overall economy and the environmental impacts of the producing economy on the natural economy. The outcome of the surveys in this direction is critical to environmental and socioeconomic issues. Among them, 1) reliable measure of ecological performance, 2) strategic planning and priority setting when designing effective policy actions, biodiversity management or formulating global climate policy agreements, 3) minimize the human, societal and financial costs of pollution, conservation costs of managing protected areas and costs of habitat restoration.

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