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AGGREGATIONAND PROJECTION OF SUSTAINABILITY INDICATORS: A NEW APPROACH

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Abstract

Sustainability has been one of the major concerns of modern societies, which have long been interested in understanding and governing the multi-faceted issue of development. A comprehensive assessment of sustainability is crucial to different categories of stakeholders, for it allows measuring progress, identifying areas to be addressed and evaluating the outcome of implemented policies. There is a wide literature on sustainability indices and indicators, used as means to assess sustainability in a quantitative and concise way. We have constructed a new sustainability index, the FEEM Sustainability Index (FEEM SI), which introduces a novel approach towards the assessment of sustainability. The novelty of our work is twofold. First of all, it addresses the problem of aggregation of sustainability indicators by implementing an aggregation methodology that focuses specifically on the interrelation between indicators. In fact weights are attributed to single indicators as well as to all possible combinations of indicators belonging to the same node. This non-additive aggregation methodology is particularly well-suited to deal with multi-attribute issues like sustainability. Secondly, the FEEM SI is built within a dynamic computable general equilibrium model, which allows projecting different scenarios in the future. The model output can then be used to assess sustainability according to the different characteristics of the scenarios. The model is based on a database relative to 2001, and is then projected up to 2020. A database depicting the state of the different regional economies is produced for each year and used to build the set of indicators that compose the FEEM SI. Thanks to this methodology, it is possible to assess how different policies would affect sustainability in the future.

KEYWORDS: Sustainability indicators, CGE models, non-additive aggregation methods

JEL CLASSIFICATION: Q01, C68, O10

1. Introduction

The debate surrounding international issues such as poverty, climate change, education standards or access to health services, is gaining increasing importance. The design of international policies has been encouraged to attempt to deal with them. In this context the need to find effective tools to measure the impact of such policies is compelling, in order to identify best practices and provide material for international negotiations. Several indicators have already been devised by national governments and international bodies to monitor progress in achieving specific goals to which policies are targeted and oftentimes the policies themselves require monitoring in order to check whether obligations are respected. However, the implementation of a policy does not affect only the activity targeted, but it contributes to the modification of the entire human environment that cannot be monitored just by verifying that its targets are met. In order to monitor the systemic effects of policies, studies are carried out within general equilibrium models, which manage a fairly detailed description of the economic world and are extendable to a variety of environmental and social aspects. In this paper we introduce a new measure of sustainability – the FEEM Sustainability Index (FEEM SI) –which exploits the characteristics of general equilibrium studies by bridging it together with a systemic theory of the world able to capture the importance of all aspects of economic, environmental and social components – the theory of sustainability.

Sustainability has been one of the major concerns of modern societies, which have long been interested in understanding and governing the multi-faceted issue of development. A comprehensive assessment of sustainability is crucial to different categories of stakeholders, for it allows measuring progress, identifying areas to be addressed and evaluating the outcome of implemented policies. Measuring sustainability requires the prior identification of its relevant dimensions and in particular of a series of indicators able to capture its diverse aspects. The sustainability literature offers one particular feature that presents interesting opportunities for policy evaluations, that is the possibility to develop one single aggregated measure of sustainability. The FEEM SI is a unique measure of sustainability built on a comprehensive methodology whose novelty is twofold. First of all, the FEEM SI addresses the problem of aggregation of sustainability indicators by implementing an aggregation methodology that focuses specifically on the interrelation between indicators. Weights attributed to single indicators as well as to all possible combinations of indicators belonging to the same node. This method allows taking into account interactions between indicators and is particularly well-suited to deal with multi-attribute issues like sustainability. Secondly, the FEEM SI is built within a dynamic computable general equilibrium model, which allows projecting different scenarios in the future. The model output can then be used to assess sustainability according to the different characteristics of the scenarios. The model is based on a database relative to 2001, and is then projected up to 2020. A database depicting the state of the different regional economies is produced for each year and used to build the set of indicators that compose the FEEM SI. This single measure of sustainability allows for a quick assessment of sustainability performance across states and, exploiting the possibility of a dynamic general equilibrium model, across time. Moreover, it manages to translate the effects of policies on the world system and convey the meaning in easy-to-read terms. Finally, it represents a tool for effective project planning, highlighting best practices and weaknesses of sustainability strategies.

This paper provides a concise overview of the methodology used to construct the FEEM SI. Section 2 deals with the methodology explaining it in its various steps, namely selection of indicators, modelling framework, normalisation and aggregation. Section 3 concludes.

2. Methodology

The FEEM SI is built on a comprehensive methodology which is divided in different steps. Indicators are firstly selected from reliable and internationally-recognised literature. Data for the indicators are then obtained from a dynamic Computable General Equilibrium (CGE) model, thus allowing projecting indicators in the future. Indicators are then normalised according to a policy target-based benchmarking methodology. Finally, indicators are aggregated onto a single sustainability measure according to a non-linear aggregation function. A sensitivity analysis is also performed in order to verify the robustness of the aggregation methodology. This section will supply a brief explanation of the different methodological steps for the construction of the FEEM SI, highlighting the elements of novelty and the new tasks this index can perform.

2.1 Selection of indicators

Dealing with the complex issue of sustainability requires the ability to frame its multi-faceted nature into an operational scheme of some kind. This conceptual framework is necessary especially in order to help focus and clarify what to measure, what to expect from measurement and what kind of indicators to use (Pintér, Hardi and Bartelmus 2005). Between all different types of indicators used in the literature, the FEEM SI has been built on theme-based indicators. These are the most used type, because they are well suited to be linked to policy processes and targets. In this framework sustainable development is usually divided in different pillars of sustainability and for each one a set of indicators is defined, following a pyramidal structure from themes to sub-themes.

The list of indicators to be included in the FEEM sustainability index has been built after a thorough analysis of the existing indicators that are commonly used to assess the progress in achieving and maintaining sustainable development. The indicators taken into consideration for the FEEM SI are obtained from recent publications of acknowledged international institutions, such as the EU Sustainable Development Strategy (EU SDS), the Commission on Sustainable Development Strategy, the World Development Indicators and the European Environment Agency, and deal with issues of public interest that in many states have also become policy objectives.

Criteria had to be defined to guide the selection process after confronting the different sources of existing indicators. Even if using well-established and accepted indicators increases the relevance of this work, it is the thoroughness of the indicator set that is most important to create an index that approximates best the concept of sustainability. The EU SDS indicator list and the indicators from the Commission on Sustainable development of the United Nations have been carefully evaluated at each level to choose what we believe are the indicators that best fit in the sustainability framework within the potentials of a CGE model. The final list of indicators is illustrated in Table 1.

TABLE 1: INDICATORS IN THE FEEM SUSTAINABILITY INDEX

Theme	*Sub-theme*	*Indicator*
ECONOMIC	ECONOMIC STRUCTURE	1. GDP per capita
		2. Consumption expenditure as % GDP
	COMPETITIVENESS	3. Total R&D expenditure as % GDP
SOCIAL	POPULATION	4. Population growth
	POVERTY	5. Share of food in primary goods consumption
		6. Energy per capita
	PRIVATE EXPENDITURE ON SOCIAL SERVICES	7. Expenditure in insurance and pensions % GDP
	EDUCATION	8. Public expenditure on education as % GDP
	HEALTH	9. Health expenditure by privates as % overall health expenditure
		10. Overall health expenditure as % GDP
ENVIRONMENTAL	CLIMATE CHANGE	11. Carbon intensity of energy
		12. Growth rate GHG emission per capita
	WATER	13. Water use as % total renewable water resources
	ENERGY	14. Energy intensity (energy/GDP)
		15. Imported energy as % overall energy use
		16. Share of clean energy in primary energy consumption
	NATURAL RESOURCES	17. Biodiversity index-plants
		18. Biodiversity index-animals

The analysis conducted to this point allowed selecting 18 indicators, which have been organised into a three-pillar scheme, a meaningful framework not only in terms of consistency with other works, but also particularly well-suited for the normalisation and aggregation techniques that will be employed. All indicators are comparable across countries, as always expressed in performance ratios or per capita measures, forms that allow us to avoid the bias coming from different country size or population.

2.2 Modelling Framework

The FEEM Sustainability Index is built within the framework of a dynamic Computable General Equilibrium (CGE) model. Building a sustainability index within an applied economic model offers the possibility to use the index for projections and policy simulations, which is not normally feasible in traditionally-built sustainability indices. Various computer models are commonly being used for the evaluation of sustainability impacts (Klaassen and Miketa, 2003) and, as argued by Böhringer and Löschel (2004), there is no specific model that would be suitable to assess all the impacts of sustainability, although CGE models are flexible in a way that they can incorporate several key sustainability indicators in a single micro-consistent framework.

The model that has been chosen for the construction of the FEEM SI is the ICES-SI model, a modified version of ICES (Inter-temporal Computable Equilibrium System, Eboli et al., 2009) created to accommodate for the creation of the selected indicators. ICES-SI is a dynamic, multi-regional CGE model of the world economy, based on the GTAP model and database (Hertel, 1997). This model is an ideal framework for the construction of a policy-oriented sustainability index. Firstly, the large database the model is based on makes it possible to calculate the index for several regions, and to create indicators using data relative to the different sectors. Secondly, the nature of a CGE model, in which all sectors and regions are interconnected, is ideal to capture the tradeoffs between different indicators. Finally, its dynamic framework produces data relative to a growth path which can be used to calculate the index in the future, and under different policy assumptions. At the present stage of development, ICES-SI allows for a medium term sustainability assessment for the period 2002-2020. The possibility to project sustainability in the future is very different from other aggregate sustainability indices, and one of the major contributions of this work. The regional aggregation of the model allows us to assess sustainability for 40 world countries and regions.

Industries are modelled through a representative cost-minimizing firm. A representative consumer in each region receives income, defined as the service value of the national primary factors (natural resources, land, labour, capital). Demand for production factors and consumption goods can be satisfied either by domestic or foreign producers which are not perfectly substitutable according to the "Armington" assumption. The dynamic of the model is driven by two sources: one exogenous and the other endogenous. The first stems from exogenously imposed growth paths for some key variables - population, labour stock, labour productivity, land productivity. The second concerns the process of capital accumulation, according to which capital stock is updated over time in order to take into account endogenous investment decisions. Emissions of other greenhouse gases, namely methane and nitrous oxide, are also included in ICES-SI. Data relative with emissions of these gases have been calculated starting from the GTAP non-CO2 emissions database (Lee, 2003). Other variables, such as water, biodiversity and renewable energy, have been added to the model database in order to construct the indicators for the FEEM SI.

The reference baseline scenario has been simulated following assumptions intended to reproduce an intermediate growth level in a world where no significant policies have been implemented. This reference point will be useful to compare and evaluate different policy options and also hypothesis about future economic, social and technological developments. Three are the main sources for the exogenous dynamics used to create the ICES-SI Baseline:

1.The WITCH (A World Induced Technical Change Hybrid) model that combines a detailed structure of the energy sector in its bottom up component linked with a top down description of the world economy divided in 12 world regions (Bosetti et al., 2006);

2. The United Nations World Population Prospects (UN, 2009); and

3. The IMAGE model (IMAGE, 2001), which is an integrated assessment model with a particular focus on land use, reporting information on seven crop yields for 13 world regions, from 1970 to 2100.

In the economic sphere, the GDP growth follows an intermediate growth path, whilst the environmental sphere considers a high emissions growth scenario corresponding to the absence of any climate policy implementation. In order to simplify the task, we have calibrated the model targeting the GDP and emissions levels from WITCH, which follows exactly the growth and emission paths described. In fact, although the two models differ in structure we have attempted to harmonise the ICES-SI baseline with the Business as Usual scenario of WITCH, giving first priority to replicating the GDP, while calibrating CO2 emissions as close as possible to those of WITCH. Two reference years are considered for this process, 2010 and 2020, interpolating the remaining years. Due to the greater disaggregation of the ICES-SI model, it has been necessary to perform a downscaling to calibrate the GDP growth rates of the model taking into account the relative size of every region in economic terms and also using the downscaling of the IPCC scenarios proposed by IIASA (IPCC, 2000). This GDP growth path has been obtained from exogenously imposed growth paths for some key variables - population, labour stock, labour productivity and land productivity. The values for these variables are taken from existing sources: available statistics or projections from other modelling exercises. The population (and labour stock) growth rates are taken from the United Nations World Population Prospects (UN, 2009). Labour productivities are calibrated to replicate as much as possible the GDP growth rate from the downscaling process derived from the WITCH model.

Energy sectors are one of the core components of ICES-SI with a detailed aggregation based on fossil fuel sources. Because of this reason, during the calibration of a baseline it is critical to consider different projections and forecasts for fossil fuel prices. This is a process that follows a regular update taking into account the current trends for those prices and also different editions of the World Energy Outlook (IEA, 2008), the International Energy Outlook (EIA 2008), and the Annual Energy Outlook (EIA, 2009). With the current prices trends and the energy agencies projections we calibrated also the stocks of the fossil resources in the model in order to reproduce the scarcity in the market and revealed through its intrinsic prices. Finally, CO2 emissions follow an analogous growth path from that of the WITCH model. In order to obtain similar CO2 emissions we have exogenously modified the energy efficiency levels in the model.

Whilst the calibration of the baseline model is aimed at supplying an average-growth no-policy scenario, the model can also be projected according to policy scenarios and to alternative growth scenarios. This gives the opportunity to calculate the FEEM SI under different policy and growth assumptions, and to compare sustainability implications between the different scenarios.

2.3 Normalisation

According to the OECD Handbook on constructing composite indicators "normalisation is required prior to any data aggregation as the indicators in a data set often have different measurement units" (Nardo et al, 2005). Several normalization techniques exist in literature and none can claim to be the best in all situations. The choice of a specific one depends on the nature of the work and needs to be carefully designed in order to fit the specific data.

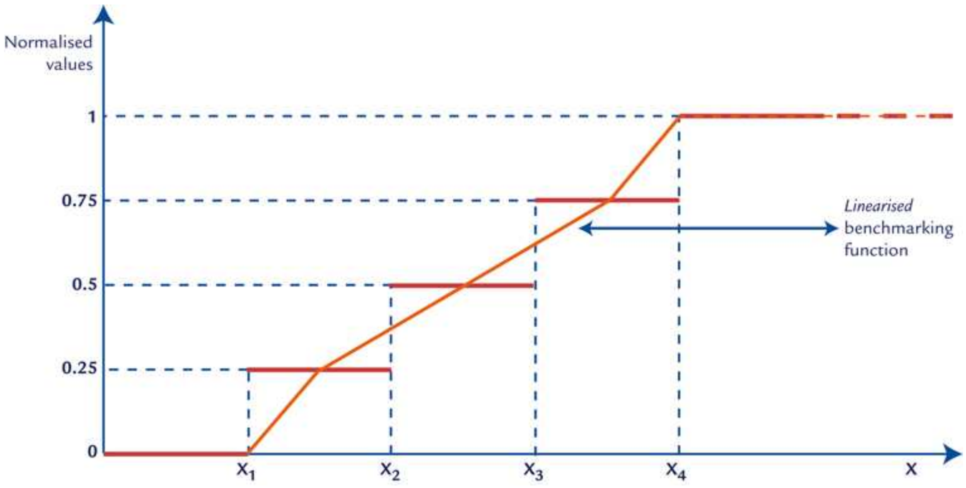
The normalization procedure chosen for the FEEM SI starts from a very simple consideration: sustainability is a well defined concept in some fields – specific policies exist to increase sustainability measured by specific indicators – and much less defined in others. The FEEM SI indicators have been translated into a 0-1 scale using an indicator-specific normalization grid defined either starting from relevant sustainability policies or on an average-based criterion. This method is called benchmarking and is very appropriate especially in the case of those indicators for which an agreed target of some kind (at EU level or global) exists. Normally, the benchmarking procedure assigns only two values, 1 and 0, according to the correspondence to a chosen reference level. In the case of the FEEM SI the purpose was not only to identify best and worst practices, but also to provide a measure of a distance from a given target. This is why five different benchmark levels have been identified, as from Table 2, and used to attribute different levels of sustainability.

TABLE 2: NORMALISATION BENCHMARK LEVELS

0	Extremely unsustainable situation
0.25	Indicator is still not sustainable but not as severely as in the previous case
0.50	A discrete level of sustainability, but still far from target
0.75	Satisfactory level in the sustainability, yet not on target
1	Target level, fully sustainable

The five different levels illustrated in Table 2 define a step function with four closed and two open intervals, each one has been "linearised", taking the mean values of two subsequent intervals and interpolating, thereby creating a continuous step function, as illustrated in Figure 1.

FIGURE 1: NORMALISATION BENCHMARKING FUNCTION



Each one of the five reference levels corresponds to a given level of sustainability, like a series of steps that go from unsustainable to fully sustainable, while values inside any of the intervals defined by these five values corresponds to an intermediate level in between two steps.

2.4 Aggregation

The FEEM SI is an aggregate measure of sustainability that allows ranking univocally world countries. Nevertheless, it is composed of very different indicators, some of which may be complementary, other conflicting or alternative. Looking at a single measure of sustainability can become a very powerful instrument to provide information able to shape effective policy measures. A central issue in creating aggregate sustainability measures lies in the credibility of the aggregation process, which should be precise enough to capture the many aspects of the problem, yet simple enough to be understand. Such aggregation process needs to rely on a sound and reliable procedure of preference reconstruction. In order to avoid the subjectivity of individual weights for subgroups of indicators, other studies rely on a simple weighted average; such a procedure completely ignores any interrelation between the different aspects of the problem- any synergy or conflict that may arise in the pursuit of one indicator with respect to the others is neglected. On the other hand, relying on subjective weights may be hard to justify, especially if the preference elicitation does not take into account the systematic bias and potential questionnaire pitfalls that an experimenter can encounter.

In light of all these considerations the FEEM SI incorporates an aggregation methodology that focuses specifically on the interrelation between indicators. For the construction of the FEEM SI weights are attributed to each indicator, and to all possible combinations of indicators belonging to the same aggregation node. The first step in doing this is to order the indicators in a logical framework in which indicators are arranged into different levels, and where indicators belonging to the same theme and sub-theme are part of the same node. This is done by building an aggregation tree, which for the FEEM SI is illustrated in Figure 2.

FIGURE 2: AGGREGATION TREE FOR THE FEEM SI

Weights are attributed to each single indicator and to all combinations of indicators belonging to the same node, at all different levels of the aggregation tree. For instance, in the economic sphere, at the lowest level a weight is attributed to Consumption, to GDP p.c. and to the combination of Consumption and GDP p.c. Then, at the higher level, a weight is attributed to Economic Structure, to R&D, and to the combination of these two, to finally arrive to an aggregate value for economic sustainability (ECON). This procedure is done for each aggregation node.

Weights are obtained as the result of a careful reconstruction of individual preferences that respects the synergies or conflicts that are naturally built into the aggregate concept of global sustainability. In other words, we reconstructed weights asking to a group of experts to evaluate how the different components of sustainability relate one to the other. Differently from other procedures, where a relative weight is defined for each indicator with respect to the others, the decision tree requires to attribute weights to the coalitions of indicators present at each node. In order to facilitate this evaluation the indicators present at each node is interpreted "at the edge" - either at their best or worst level - creating a matrix of all the possible combinations between these two levels of the indicators. To illustrate this, let us consider an example in which we are dealing with the attractiveness of a restaurant according to three indicators, namely average price of a dinner (price), quality of the food (quality) and kindness of the staff (kindness). For each indicator let us imagine two extreme levels which will be called "best" and "worst". The matrix of all possible combinations of the indicators chosen at these two levels is illustrated in Table 3. Note that, the first and last row must necessarily be valued 0 and 100, whereas the other row only need to respect the monotonicity criterion[1] and may lie between 0 and 100.

TABLE 3: AGGREGATION MATRIX EXAMPLE

Price	Quality	Kindness	Weights
Worst	Worst	Worst	0
Best	Worst	Worst	20
Worst	Best	Worst	50
Worst	Worst	Best	30
Best	Best	Worst	X ≥ 50
Best	Worst	Best	X ≥ 30
Worst	Best	Best	X ≥ 50
Best	Best	Best	100

Once weights are obtained for all the needed coalitions, they are used in a special weighted average called the Choquet integral, which is a tool particularly well-suited to deal with multi-attribute issues like sustainability. The weights given for each interaction are combined to define the Choquet integrals and compute the total score for the FEEM SI.

A sensitivity analysis has been performed on the weights to check on the robustness of the methodology. For the construction of the FEEM SI we use subjective weights obtained from a simulated *andness*-biased decision maker. An *andness* decision maker believes that different indicators are not substitutable, and that in order for a country to be sustainable it should have a high score in each of its component of sustainability. This is based on the very concept of sustainability and the *andness* nature of sustainability has a primary role in our aggregation methodology. Nevertheless, it is interesting to see how sustainability would vary considering a situation in which the decision maker features different preferences, for instance having *orness* traits -that is, he is satisfied when only one criterion is satisfied. Such a decision maker clashes markedly with the simulated decision maker used for the aggregation in the pilot version of the FEEM SI. In fact, *andness* and *orness* represent two opposite ways of looking at multi-attribute problem that cannot be meaningfully compared. Therefore, when investigating the robustness of FEEM SI one may start considering reasonable variation in the general attitude of the decision maker, changing the degree of *andness* with which weights were constructed. The sensitivity analysis approaches this problem by considering the results for the FEEM SI under different levels of *andness* for the decision makers.

3. Conclusion

The FEEM SI is a novel sustainability index aimed at enhancing the application of sustainability indices to policy studies. The FEEM SI is based on a solid and innovative methodology. In particular it introduces two novelties. Firstly, it combines indicators with a non-additive aggregation method able to capture interactions between indicators. Secondly, being built within the framework of a dynamic computable general equilibrium model, it offers the possibility to project sustainability in the future and to compare it across different growth and policy scenarios. The FEEM SI allows us to rank countries according to their sustainability performance, and to check the future sustainability paths for the different countries and regions, and under different policy and growth scenarios. This increases the operability and applicability of the FEEM SI as it allows assessing whether a chosen policy would have a positive of negative effect on overall sustainability.

[1] Monotonicity requires that a combination of indicators having both "best" levels is evaluated at least as high as the single indicators having "best". This is due to the fact that all indicators are already normalized from in a 0-1 range where 0 is the worst score and 1 the best.

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