QUANTITATIVE SIMULATION OF COMPREHENSIVE SUSTAINABILITY MODELS AS GAME BASED EXPERIENCE FOR EDUCATION IN DECISION MAKING

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ABSTRACT
Sustainability knowledge and skills are highly regarded competencies by many companies and organizations. Sustainability can be seen as an additional requirement that business/system must satisfy. The main contribution of this paper is to propose a quantitative method for modeling and integrating sustainability issues in the analysis of business alternatives in building a coal power plant in a port area.
The authors have developed a sustainability model implemented in a simulator which has been used as a tool in a role play game experience; the paper describe the simulator as well as its experimentation within the Genoa University MIPET Master Program for addressing innovation in Industrial Plant Engineering and Technologies.

Keywords: Sustainability, Power Plant Projects, Economic and Environmental Impact Model, Play-Based Experience, Multi-Party Negotiation, Simulation in Negotiation Education.

1. INTRODUCTION

According to the Brundtland Report, a "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. Guaranteeing a sustainable development of our society is one of the emerging problems that humans have to face. This challenge requires a multidisciplinary approach in which researchers, professionals and politicians with different backgrounds, and often belonging to different group of interests, combine their efforts.
Addressing sustainability is becoming a crucial capability in companies or governmental organization. There is a need to define competencies that are useful to train future professionals in this area and to develop a strong community of practice. Individuals leading sustainability in organizations or firms must be able to measure the impact of sustainable initiatives, properly master the dynamics of offsets and compensations between the interests of the various stakeholders.
Universities are embedding sustainability into existing engineering courses since the demand of related professionals and experts is expected to rise in the near future. In the framework of the well-established Master level course in Industrial Plants (MIPET) held by University of Genova it has been decided to complete the sustainability notions with practical activities by mean of a simulated environment.
Focus of the paper is to describe the sustainability model behind the simulator MOSES (MOdelling Sustainable Environment through Simulation, Lio Tech Ltd) which has been used as a tool in a game based experience during a MIPET class. The simulator has been used by competitive groups of students to assess in a quantitative way the sustainability of a virtual scenario of port area housing a power plant, a military base and industrial facilities close to a populated area. In particular, during the game based experience, the simulators allowed to quickly evaluate different scenario configurations and to quantitatively assess mitigation measures of the impacts. A section will be devoted to the description of the game based experience and the simulation of negotiation process of tradeoffs between stakeholders.

2. A SUSTAINABILITY MODEL

Sustainability: a SoS approach

It is important to notice that sustainability is studied and managed over many levels of time and space and in many contexts of environmental, social and economic frames of reference. For example it is possible to examine sustainable development of the whole globe, a country or a region. As the scale becomes smaller, it is more difficult to address sustainable development [2]: the above mentioned area which has been modeled in MOSES, for instance, cannot be examined without taking into consideration the interactions with the region and the country it

belongs, for instance the national regulations and policies.
Because of the nature of its impacts, sustainability interfaces with economics through the social and environmental consequences. Modeling sustainability implies the ability to model sustainability economics which involves ecological economics where social aspects (cultural, health-related) and monetary/financial aspects are integrated [3][4][5][6][7]; these context are obviously very good examples of complex systems [8][9][35][36]
Some sustainability models available in literature consider as inputs a homogeneous set of quantities drawn from a single aspect of sustainability, such as environmental system or the social one [2]; indeed there examples were multiple aspects were considered combining for instance environmental and economics impacts with operational issues [23]. MOSES is moving forward to embed a comprehensive approach able to qualify each scenario with several indexes (outputs) at a time using a scalable architecture [29] [34].
The authors reckon that a valuable approach to model sustainability combines necessarily the human and the ecological system. The human system consists of the economy related to such aspects as health, work, economy, education and policies while the ecological system consists of air, land and water [2] [28]. This is a system of systems (SoS) approach, as shown in Figure 1.
Among the indicators, belonging to different systems as in Figure 2, MOSES is able to calculate classical sustainability scalars, like the carbon footprint, which allows eventually comparisons with other models. The concept of ecological footprint, introduced in [24] and developed in [25], is a valuable indicator of ecological sustainability of a system or an activity. Taking into account resources that a population/activity exploits and the main wastes generated, it is possible to convert them into a corresponding land size needed for the assimilation of the above mentioned quantities. In MOSES simulator, as suggested in literature [26], [27], the carbon footprint (also referred in this paper as [CFP]) has been modeled considering the assimilation of the equivalent CO_2.
The indicators/variables that have been taken into consideration for this model are listed in Table 1.
Our model assumes that an established port area is subject to some development proposals, with concurrent actions to be performed on its main activities. In order to set the simulation in a realistic environment the model has been tailored on a city populated by about 95K inhabitants, facing the Tyrrhenian sea, and with one commercial and military port, hosting the arsenal of a Navy. The urban area extends over 52 km^2 and includes a power plant, equipped with 2 combined cycle gas turbines and a coal-fired unit, for a total output power of about 1.3 GWe.

Table 1: List of all the modeled variables in MOSES simulator and their system aggregation.

Variables	Units	**System of Systems**					
		Human System			**Environment System**		
		Economic System	**Resource Consumption System**	**Health System**	**Land System**	**Air System**	**Water System**
[POWER PLANT]	MW	X	X				
[PLANT AREA]	m^2				X		
[BASE AREA]	m^2				X		
[INDUSTRY AREA]	m^2				X		
[TOWN AREA]	m^2	X		X	X		
[GRASS AREA]	m^2			X	X	X	
[FREE AREA]	m^2			X	X	X	
[SURFACE]	m^2	X		X	X	X	
[PLANT CO_2 EMISSION]	Mkg/y		X	X		X	
[PLANT WORKERS]	people	X					
[BASE WORKERS]	people	X					
[INDUSTRY WORKERS]	people	X					
[TOURISM WORKERS]	people	X					
[OTHER WORKERS]	people	X					
[UNEMPLOYED]	people	X					
[TOT WORKERS]	people	X					
[SALARY]	€	X					
[POPULATION]	people	X		X	X		
[COAST QUALITY]	#			X			X
[GREEN AREAS]	m^2			X	X	X	
[CFP]	m^2			X		X	
[QUALITY AIR]	#			X		X	
[PLANT SALARY]	€	X					
[BASE SALARY]	€	X					
[INDUSTRY SALARY]	€	X					
[TOURISM SALARY]	€	X					
[OTHER SALARY]	€	X					
[UNEMP SALARY]	€	X					
[DISEASES]	€	X		X	X	X	X
[DEATHS]	#/y			X	X	X	X
[PLANT PROFITS]	€	X					
[HAPPINESS]	#	X		X	X	X	X

Environmental impact, and thus sustainability issues, for a plant so close to the residential areas are a major concern for both the electrical utility and the population, due to the emissions and the possible degradation of air quality.
The military base, on the other hand, is less impacting from the environmental point of view, but extends of a big share of the available territory. Both realities have a strong impact on the occupation of the inhabitants and on the local economic framework.

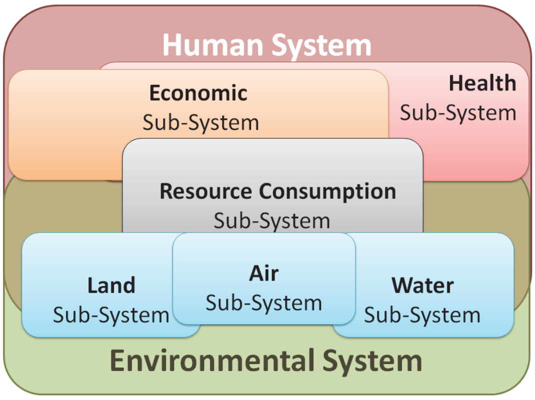

Figure 1: SoS Architecture

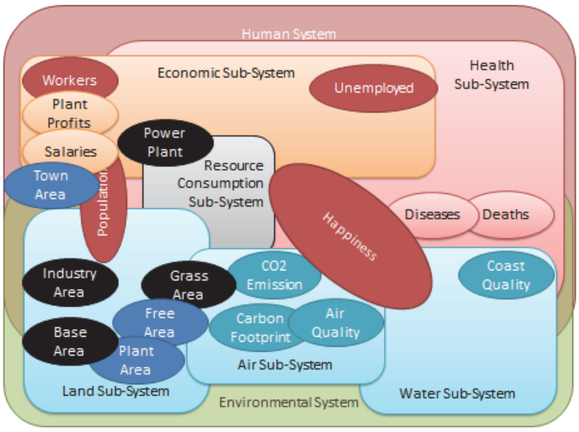

Figure 2: SoS Architecture with MOSES variables grouping

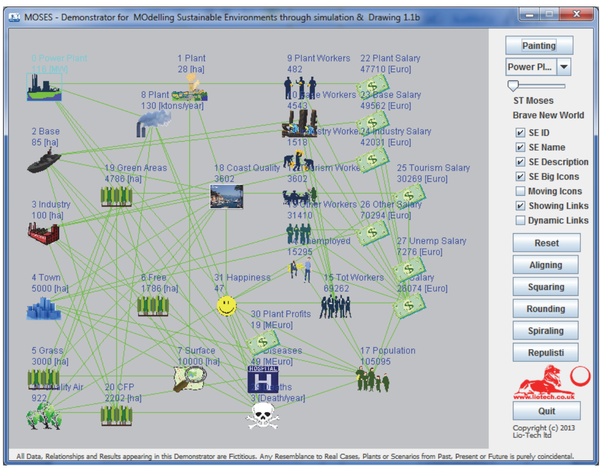

Figure 3: MOSES main interface showing variables and functional dependencies (green links)

Model variables: dependency nodes and links

Even in the context of a simple model, due to the complexity of the phenomena involved in this real-world description the modeling requires two orders of discretionary choices:

- The state variables,
- The functional dependencies liking them.

The choice of the variables should be done according to the following principles [11] :

- Pertinence principles: indicators should be pertinent to the studied object;
- Representative principle: the indicator system should be representative of the economic development, resource consumption and environmental pollution;
- Availability principle: the data for the indicators should be available from statistics;
- Comparative principle: the selected indicators should be comparative in temporal, spatial and data source aspects.

The functional links constituting the mathematical skeleton of the model derive from literature and the field experience of the authors and are shown in Figure 3. Generally highly non-linear, they often represent the effect of the other state variables with exponential laws modifying a hypothetical equilibrium state.
The model has been conceived with four major independent variables that are presented in Table 2. The value of these indicators is under control of the user; the overall resulting model results in a non linear complex function starting from fourth-dimensional space of input and addressing a twentyseventh-dimensional space representing the consequent output configuration.

Indicators	Direct functional dependencies
[POWER PLANT] User input. This independent variable expresses the power of the coal power plant in MW. It varies from 80 to 1000 MW.	[PLANT], [PLANT CO_2], [PLANT WORKERS], [PLANT SALARY], [DISEASES], [DEATHS], [PLANT PROFIT]
[BASE] User input. This independent variable is the land in m^2 occupied by the power plant.	[SURFACE], [INDUSTRY WORKERS], [COAST QUALITY], [CFP], [BASE SALARY], [DISEASES], [DEATHS].
[INDUSTRY] User input. This independent variable is the land in m^2 occupied by the industry.	[SURFACE], [INDUSTRY WORKERS], [COAST QUALITY], [CFP], [INDUSTRY SALARY], [DISEASES], [DEATHS].

[GRASS] User input This independent variable is the land in m^2 occupied by the industry.	[SURFACE], [OTHER WORKERS], [POPULATION], [COAST QUALITY], [CFP], [TOURISM SALARY], [DISEASES], [DEATHS]

Table 2: Independent variables in MOSES and their links.

The simulator is also equipped with a mapping tool which visualizes the use of the soil in terms of intended use, superimposed to a satellite picture (Figure 4). Figure 5 shows an example of such features which are of help to the user to get the quantitative overview of the area subdivision; in the future it could be interesting to introduce this approach within innovative crowdsourcing approaches using web technologies [13][14]. The total area is divided into colored areas according to the intended use of the surface: light blue for the power plant, red for the military base, black is the available surface, blue is the sea, yellow the industry and green is the maximum available green area (grass) needed to compensate the emissions of the power plant, if available.

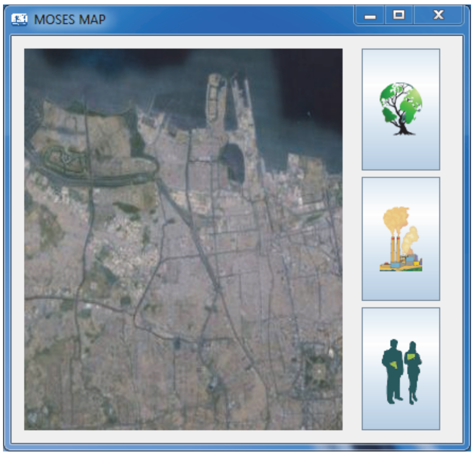

Figure 4: Satellite image of the MOSES's modeled area

3. CASE STUDY: GAME BASED EXPERIENCES ON SUSTAINABILITY

The MIPET program

The Master in Industrial Plant Engineering and Technologies (MIPET) is a one-year post-degree specialization program held by the University of Genova. This course aims at forming the new generation of top technical professionals in process engineering, industrial plant engineering, power generation and energy industry. The master program is directed by the faculty of engineering in strong cooperation with leading companies operating in several industrial sectors, setting this initiative in the international scenario.

In parallel to an intensive technical skill development program, this master also offers students a grounding in modeling and simulation for industrial processes and decision making. This course helps the students to cultivate their attitudes to critical thinking and effective management of all phases of an engineering project (offering, engineering, purchasing, construction and commissioning), also giving them an complete overview of complex activities.

Students begin their MIPET program taking the Operative Modules, followed by Thematic Modules on specific plant sectors (for example "power" and "steels are two tracks) and finally completing their knowledge on the field with an internship in one of the partner companies company, gaining at the same time a valuable experience which can be readily valorized in their curricula.

Operative modules integrated within the master program are dedicated to project works in which individual student and/or teams of student dynamically interact in a competitive/cooperative framework with experts. In particular, the operative module "R&D Projects/Innovative Technologies, Techniques and Methodologies for Industrial Plants" addresses the research and development connected to the industrial plants, in terms of competitiveness and risk analysis.

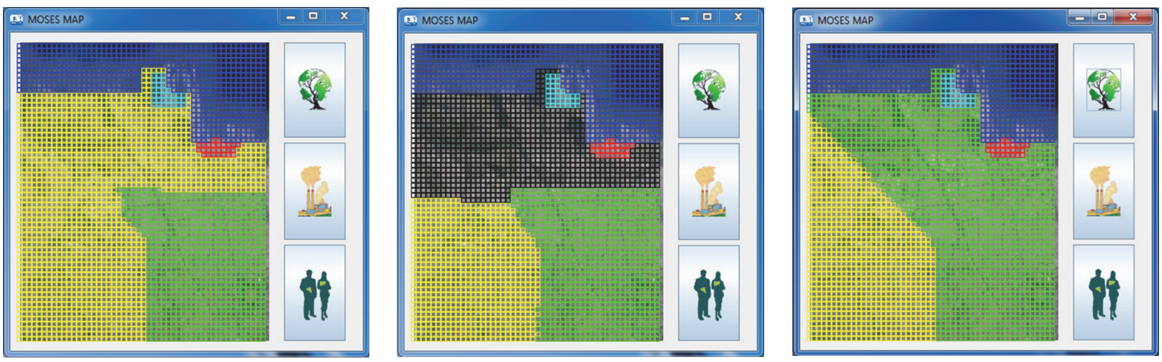

Figure 5: MOSES mapping tool in different scenario, with different inputs

This module includes a case study in which students learn and apply innovative techniques for sustainability in the industrial framework by means of simulation, using the MOSES environment. This case study requires the synergic use of notions of engineering technologies, strategies and practices to efficiently optimize energy consumption, reduce land occupation and mitigate the environmental impact [15][16]. It is organized as a game based experience, thus allowing an hands-on activity which leads to fast learning and effective assimilation by the students of the contents.

Case study on Sustainability and game based experience

In the following, the aforementioned game based experience is introduced, with particular emphasis on methodology.

The approach pursued in this paper, aligned with similar studies [17], is based on quantitatively representing the sustainability effect of a business or design alternative, in order to train engineers and professionals to understand the value of tradeoffs [18]. For this purpose, game based experiences in higher education, in particular in engineering, have proven to be successful for six major reasons [19][20] according to the teachers who have extensively used them:

1 - enhance student motivation to learn and student interest in the topic, the course, and learning in general;
2 - enhance students' concept learning, decision-making skills, and systematic analytical skills;
3 - improve future course work;
4 - trigger affective learning of the subject matter by changing students' perspectives and orientations, and increasing their empathy and appreciation of others' circumstances;
5 - enhance participants' self-awareness and self-confidence;
6 - promote better student–student and student–teacher relations.

Furthermore it is of particular interest the integration of sustainability aspects that affect professional engineering decision-making into master level courses since traditional engineering decision-making is relatively narrowly focused and tied to many contemporary environmental problems [12]. The advent of sustainable engineering requires a broader systems perspective and a more complex system tradeoffs and priority setting competencies.

The main contribution of this simulator is to show a preliminary model of integrated sustainability that can be used in the analysis of business alternatives in the early requirements analysis phase of a power plant project, sited in a specific geographical area.

Participants of the game based experience

The one day long experience took place at University of Genova and was the final assessment of the knowledge acquired through the lessons of the mentioned Operative Module focused on Innovation for Industrial Plant Engineering and Technologies during the 4th edition of MIPET Master Program [21] [38][39]; indeed use of M&S as support for training and education have a great potential and it usual a very power approach to be embedded in class experiences, team working and role play games [32][33][37] .

The experience included 15 MIPET students who worked in two groups. All participants were randomly assigned to the roles. In the experience students were supervised by professional engineers with professional background in the field. One group played the role of the governmental authority of the region, and were equipped with the MOSES environment. The second group took care of the interests of a company which aims at building and operating a coal power plant in a specific virtualized area and economic scenario. These team members were acting as the engineers who had to make the technical proposal and draft the design document including the environmental impact assessment. The latter also used MOSES simulator, obviously with a prevailing interest in a subset of output variables which was different from the one of the previous and more profit-oriented, while the former focused on social indicators. The goal of the two groups was the negotiation on the offsets and to adopt winning strategies [30][31].

The governmental authority had also to identify the requirements to license the construction of a coal power plant. These requirements needed to meet not only the interest of the local community, measure of which could be the sustainability modeled by the simulator, but they also embed the policies of norms and (i.e. emissions, water pollution, noise impact etc).

For an example of negotiation performed, it is worth noting that MOSES is able to forecast the amount of greenhouse gases emissions of a defined system or activity, considering all direct and indirect sources. Greenhouse gases emission are often expressed in terms of the amount of carbon dioxide (CO_2) with an equivalent greenhouse effect. Once the size of a carbon footprint is known, a strategy can be devised to reduce it, e.g. by technological developments, carbon capture, consumption strategies, and others. Indeed, the mitigation of carbon footprints passes through the development of alternative projects, such as reforestation or green grass areas (carbon offsetting). The quantification of these compensating measures was one of the objects of the game experience.

Procedure of the game based experience

The experience was conducted in two stages. During the first one the participants used the simulator and came up with a strategy to address the problem of sustainability according to the interest of the group they were representing. Each group had analyzed different solutions and, after an internal brainstorming process, they chose the optimal solution and related tradeoffs to be shown the other group. During a second phase the two groups had to converge to a single scenario with a negotiation process. This phase allowed to train students' sustainability-specific decision-making skills.

Negotiation: methodology and experimental analysis

Given the four input variables described in section 2, each group of students had to perform a multivariate study trying to minimize their own target function. In

order to do so, the method of Analysis of variance (ANOVA) with contrast matrices seemed to the two groups the more standard and robust methodology to estimate the sensitivity of each output parameter to the different input scenarios.
Each group has selected a subset of output variables which, in their opinion, would have the highest sensitivity to their targets. The following variable grouping has been suggested by the students during the experience:

- Variables of interest for the Company: Plant, Plant Profits, Plant Workers, Plant Salary, Industry Workers, Industry Salary, Base Workers, Base Salary.
- Variable of interest for the Authority: Happiness, Coast Quality, Air Quality, Green Area, Diseases, Unemployed and Population.
- Variables that the Company considered useful for mediation with the Authority: CFP, Free, Other Workers, Other Salary, Total Workers, Salary, Surface.

After the analysis, the simulation pool has been represented by a polar graph, clearly indicating the best solution. Figure 6 shows the graph with the seven variables results of the sensitivity analysis of the Government group. Through many trials the group found the optimal scenario (red one)

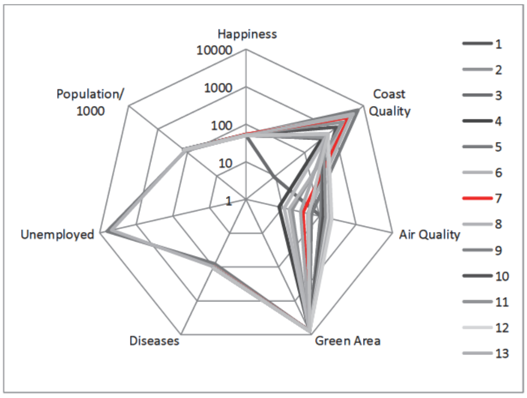

Figure 6: Polar graph of the Government group trials, with the relevant variables and the optimal scenario identification(red one)

4. CONCLUSIONS

We have presented a first attempt to treat sustainability of a port area, with a power plant, an industrial activity and a military base with the use of MOSES simulator. The simulator has been designed using the indicators and mathematical models connected to sustainability. We have faced some research challenges in order to successfully develop and test our model, such as finding the right level of detail, difficulty to incorporate quantitative data and lack of standard measures for sustainability.
Our simulator MOSES was able to quantitatively represent the sustainability of different design alternatives. MOSES allowed to properly conduct a game based experience, in which two groups of students of MIPET program, understood the tradeoffs between sustainability and other business goals and made informed decisions. The negotiation game permitted to train sustainability-specific decision-making skills. We believe this represents a first step in the contribution to the challenge of training young engineers and, to some extent, to ensure a sustainable development of our society.
We plan to continue this research line and, finally, we would like to apply our approach on new real case studies.

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