Modeling Logistics & Operations in a Port Terminal for Environmental Impact Evaluation and Analysis

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Keywords: *Simulation, Sustainability, Logistics, Environmental Impacts*

ABSTRACT

The research proposes a new methodology to analyze and evaluate the Environmental Impacts (EIs) and efficiency on Operations & Logistics by using Modeling and Simulation (M&S). In particular the authors developed models for analyzing these aspects and create the GreenLog (Green Logistic) simulation framework based on web technologies in order to define and evaluate environmental impacts (i.e. air emissions, power consumption, etc.) over supply chains and logistics networks. GreenLog allows to estimate quantitatively all the different EIs in order to evaluate different strategies and solutions for improving the supply chain in term of efficiency and sustainability, including productivity and costs aspects. As matter of fact, in this context, it is critical to identify effective and competitive solutions able to reduce EIs (i.e. resources consumption, garbage/waste disposals, noise, discharges, spills) without loosing efficiency and competitiveness.

In this paper the authors propose a case study, in order to evaluate EIs within a port terminal and to compare different solution over different KPIs

1. INTRODUCTION

In recent years, people environmental attitudes are changing due to major attention and sensitivity towards environmental issues that are increasing health consciousness and motivation to preserve environment for the next generations (for instance consumers, for ecological reasons, prefer to stop buying products from companies that cause pollution) [1] [36].

Therefore many companies are moving toward more sustainable structures and infrastructures by valorizing their own environmental performances and sustainable solutions in order to correspond to users needs and requirements. In addition new governmental laws or international pacts (such as Kyoto Protocol, White Book on Transportation, ISO 14000 Series, European Regulation 761/2000-EMAS, Ecolabel) press the different economic sectors in increasing their regards for the environment [7] [26]. In particular as concern for the environment issues, companies must take into account climate changes, air pollution, noise, vibration and accidents as well as logistics costs in order to achieve a more sustainable balance among economic, environmental and social objectives [20].

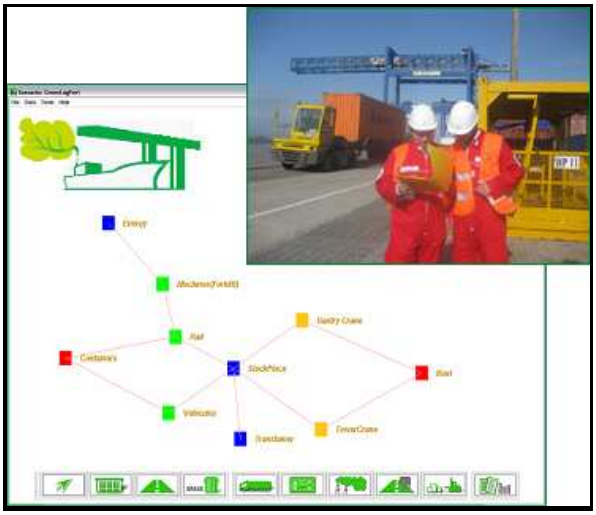


Figure 1.SimulationTeam staff member working on Collecting Data for GreenLog Port Simulator

A critical aspect is represented by Logistics due to the fact that it is related to all the activities required for moving products through the whole supply chain, from the raw materials acquisition to the product realization and distribution to the point of consumption and the associated reverse logistics [6]. As matter of fact, logistics represent a complex framework due to the many different activities and interactions with all the internal processes and external supply chain operations and it strongly impacts on environment by causing indirect costs and resources consumption [5] [14].

Therefore it is fundamental to identify supply chain management practices and strategies that allow environmental impacts and energy consumption reduction, but generally these solutions are evaluated based on experts feelings or qualitative analysis.

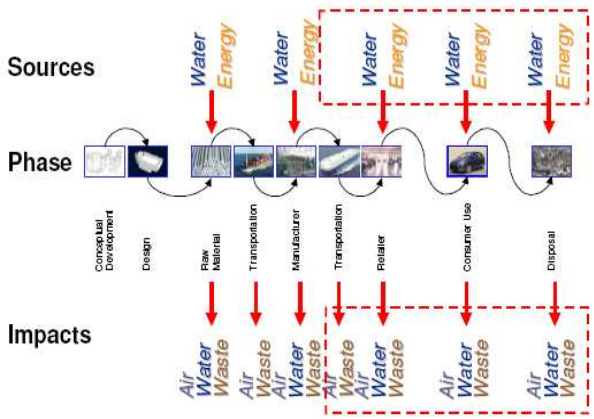


Figura 2. Source and Impact of Supply Chain

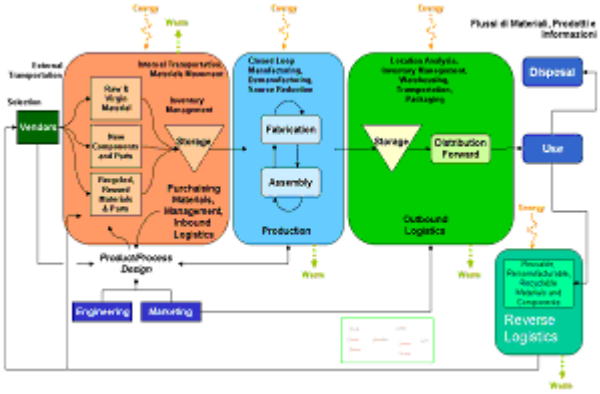


Figure 3. Logistics & Green Logistics Complex Framework

The authors propose a decisions support tool able to provide quantitative analysis and measures of the environmental impacts of the whole supply chain [1][17], by considering air emissions as well as waste disposals (i.e. rubber due to tire trucks consumption) terrain degradation, noise, spills, dusts etc. In addition the sustainability analysis includes many KPIs (Key Performance Indexes) such as that one related to costs analysis in order to find an efficient solution that considers both environment, quality, efficiency and economic aspects of the logistics networks[10].

In fact complex phenomena, different factors and processes (i.e. international regulations) need to be considered for environmental impacts estimation of the whole supply chain, so Modelling and Simulation is an ideal approach for investigating these complex system, with many components that interact each other [4] [9].

The authors propose an application for EIs evaluation in a Port Terminal by using the Green Logistic simulator (GreenLog) developed by the Simulation Team since 2008 to face these issues. GreenLog was developed orginally within the project "Italian Green Logistics Initiative" that involved Industry, Academy and Governmental Institutions in order to provide innovative solutions for "greening" improvements for the logistics and for measuring environmental impact and costs efficiency on a specific supply chain.

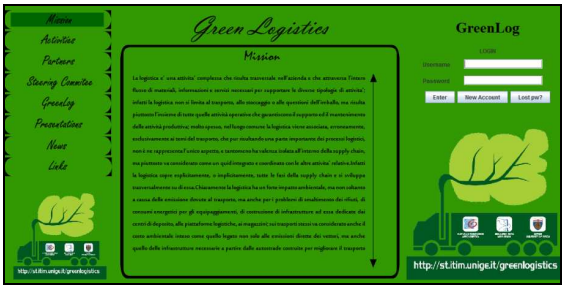


Figure 4. GreenLog Web Interface

2. THE GREENLOGISTIC SIMULATOR

Simulation Team developed GreenLog Simulator for Analyzing Environmental Impacts in Industrial and Logistic networks including for instance Production and Distribution Centers, Storage and Terminals [8].

GreenLog is a Web Based Simulation Engine including models related to performance, costs and Environmental Impacts of the Productive, Logistics and Transportation Elements along the Supply Chain. GreenLog application is owned by Simulation Team and the GreenLogistics framework is available on MISS DIPTEM web portal (www.itim.unige.it/greenlogistics) where it is possible to access to several services:

- Company Qualitative and Quantitative Questionnaire
- EIs Self Measure of the Company Logistics
- Green Level based on automated configuration of the specific simulation model
- Supply Chain Simulation for measuring impacts and performances.

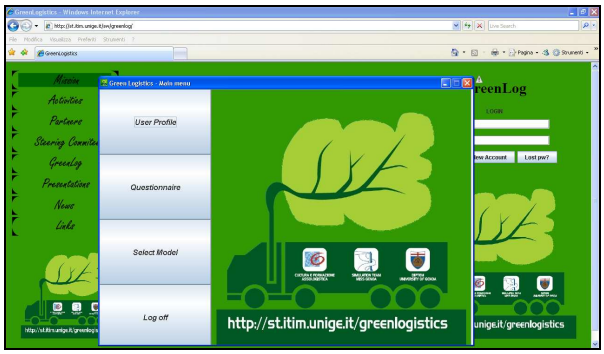


Figure 5.GreenLog Web Services

As further development, since 2008, the authors developed different modules focusing on specific aspects (www.mastsrl.eu/solutions/greenlog):

- GreenLog Port, devoted to support estimation of Environmental Impact in Ports Garbage & Port Waste, Dredging, Dust, Noise, Ship Air Emissions, Air Quality, Hazardous cargo, Bunkering, Port development, Ship Discharge
- GreenLog Ship, devoted to analyze the Environmental Impact of the Ship for supporting monitoring, alternative evaluation, saving and benefits from different solution in use, handling, operating as well as in Ship Design
- GreenLog Crane, devoted to analyze the Environmental Impact of Cranes and Handling Devices considering Operative Costs and Environmental Impact; to estimate the benefits provided by innovative solutions in term of power saving, oil spill reductions, better safety procedures and higher performances
- GreenLog Heavy Haul devoted to analyze the Environmental Impact of Trucks and Heavy Hauls considering Operative Costs and Environmental Impact.

These researches propose opportunities to apply GreenLog in different case studies; for instance Greenlog Port was applied to model EIs some Italian Port Terminal.

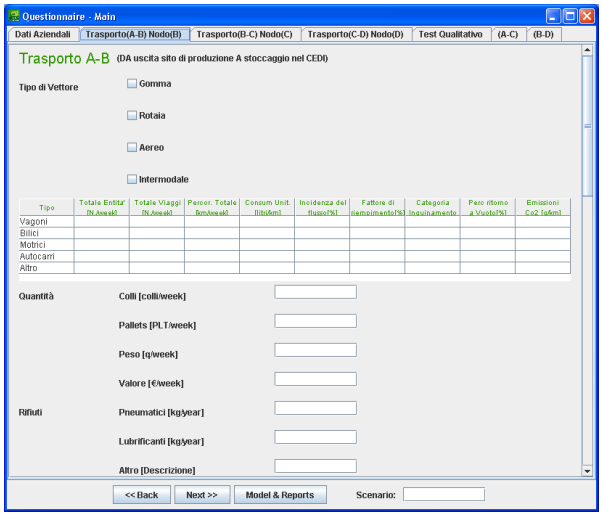


Figure 6. Example of GeenLog Web Questionnaire for Companies

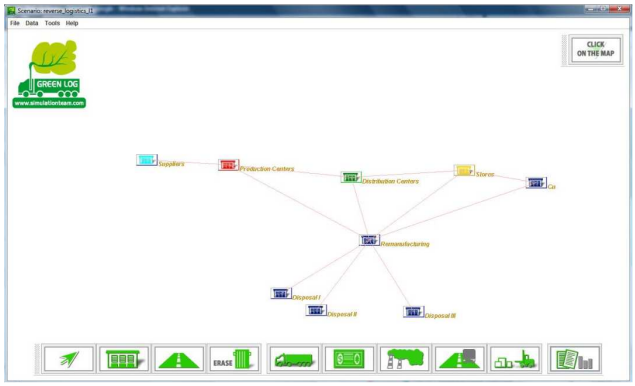


Figure 7. Scenario in GreenLog Simulator

Therefore the Green Log Simulation Models are based on the following main objects devoted to reproduce infrastructures, resources, processes and performances:

- Logistics Node (i.e. a terminal or a distribution center, a production center etc.)
- Logistics Link between two nodes
- Vector (i.e. truck, portainer, ship etc)
- Equipment (i.e. HVAC, Forklifts, etc.)
- Logistics Flows (goods and products)
- Environmental Impact (EI)

GreenLog users are allowed to create and configure the objects by Green Log GUI (Graphical Users Interface) that provides charts and diagrams reports and EIs visualization on the logistic network, in order to identify critical factors. In addition users are able to attribute Environmental Impacts to a node or to a link or to a vector and they could include emissions, disposals, power and water consumption etc.

Each EI can be constant or dependent on distance, time, flow volumes, flow type. Vectors characteristics (ships, trucks, trains, transtainers, gantry cranes, reach stackers), Node information and Links definition (i.e. terminal to yard or to transhipment) are input data for the simulator. It is possible to visualize impacts over the whole supply chain by graphics and quantitative reports and to find out the critical path by graphical representation, in order to make hypothesis and find a solution to mitigate the Environmental Impacts.

3. ENVIRONMENTAL SUSTAINABILITY IN A PORT TERMINAL

The concept of sustainability is related to the policies and strategies for using resources in order to not deplete the resources themselves. Among most popular definitions of sustainability it is well referenced that one presented at United Nation Conference in 1987, defining "sustainable developments" as those that "meet present needs without compromising the ability of future generations to meet their needs"(WECD, 1987) [18].

Therefore economic and social development should take into account of natural land, water, and energy resources saving as integral aspects of the development.

In a Port Terminal the sustainability concerns with innovative solutions and technologies for greening existing port operations and pursuing green development opportunities. In particular the main Environmental Impacts are related to:

- Definition and adoption of Sustainable Engineering Design and Construction Guidelines
- Energy and Water Conservation Policy
- Waste disposals from ships and terminal operations
- Air Quality
- Training on Sustainability

It is possible to face these issues by implementing pollution prevention measures, by identifying, for instance, waste streams to be recycled and new technologies and solutions for minimizing negative impacts on the environment and surrounding communities, by applying clean air Actions, by green buildings based on renewable energy etc.

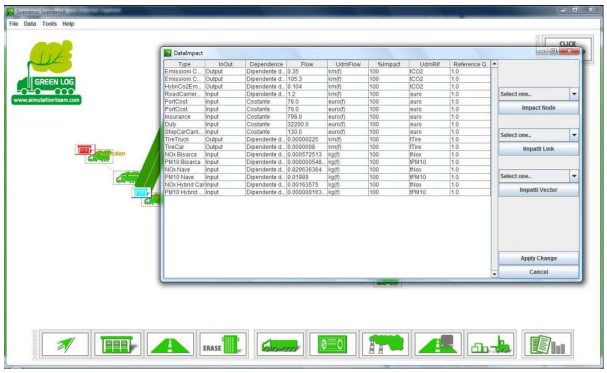


Figure 8. Environmental Impact Parameters

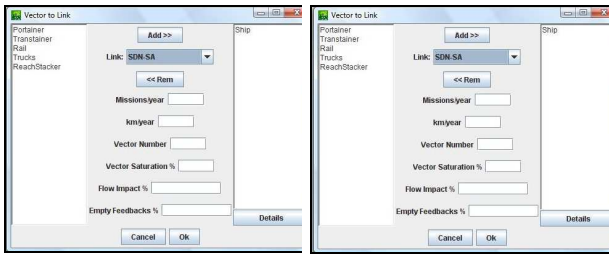


Figure 9 Nodes and Link Modeling

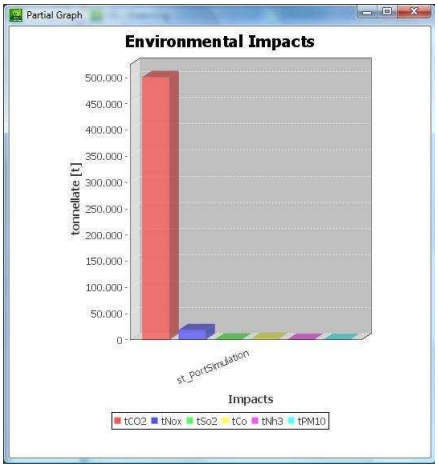


Figure 10.Environmental impacts

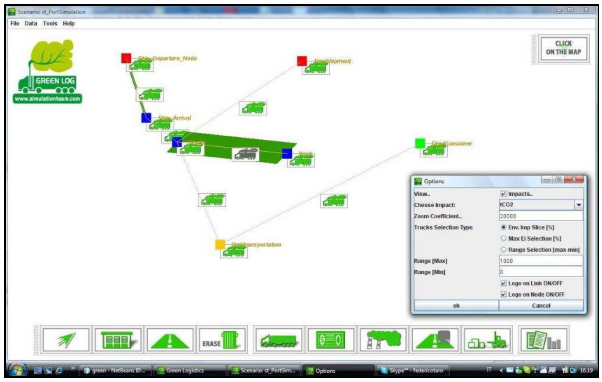


Figure 11. Impacts in Port Terminal Scenario

The authors propose a case study by analyzing:

- the environmental benefits of a new technology at the gate for control operations in order to reduce trucks waiting time and so air emissions at the gate
- the effect of rail infrastructures improvement
- the benefits of using low sulphur fuel for ships, instead heavy fuel while in operating in the port terminal

In particular the first aspect is very critical in terms of EIs. In fact the required waiting time for control operations at the gate could vary from 45 minutes to more than several hours by causing negative impacts on air quality due to trucks air emissions.

Therefore new technologies and methodologies are adopted to reduce control operation time such as the container pre-clearing that allows to know the container required information before its arrival.

The authors compared in their analysis traditional solutions, for instance based on a mechanical seal, respect new ones (i.e. use of an electronic seal based on reusable RFId tag) as well as different management strategies (i.e. sharable common tracks among different port terminals at the same gate).

Another important aspect is related to the shift from trucks to trains for import/export activities; in fact this is relevant from an environmental point of view. Obviously ship fuel is an important issue too and eve already widely in evaluation; this third aspect has a great impact on Sulphur emissions.

As it will be described in the next paragraph, the authors developed a Port Terminal Model and analyzed EIs by using GreenLog Simulator in two different cases.

4. PORT TERMINAL SIMULATION MODEL AND EXPERIMENTS

The authors developed a conceptual model for the Port Terminal to be analyzed by defining entities and environmental impacts characteristics.

A scheme of the proposed conceptual model is represented in figure:

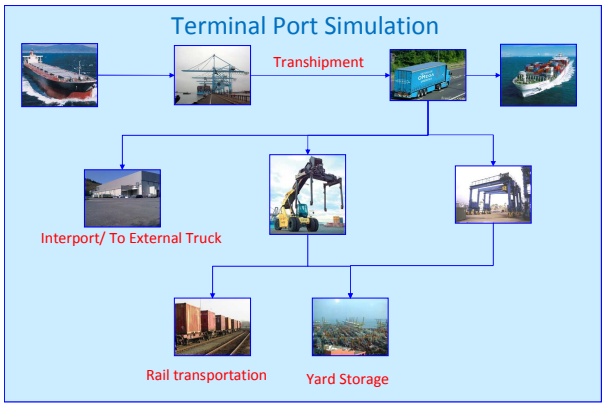
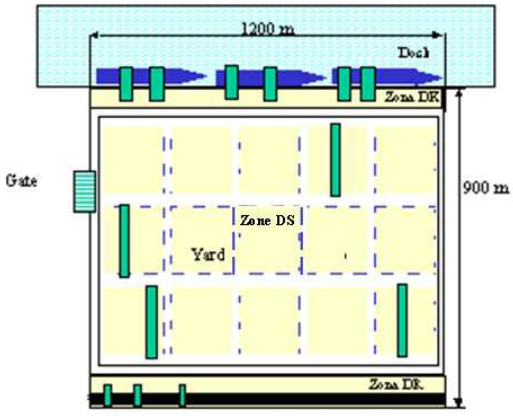


Figure 12. Port Terminal Simulation

The Port Terminal includes:

- Zone DK for Dock Operations
- Zone DS: Yard / Storage Area
- Zone DR: Rail Terminal



The flows are managed in accordance with the following directions:

Import

From Ship To Feeder Ship

Ship ⇒ DK ⇒ DS ⇒ DK⇒ Ship

From Ship To Train

Ship.⇒ DK ⇒ DS ⇒ DR⇒Train

From Ship To Truck

Ship ⇒ DK ⇒ DS ⇒ Truck_Out

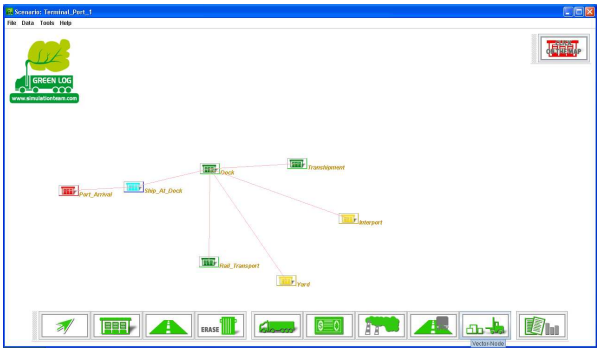


Figure 13. Port Terminal Model

Export

From Feeder Ship to Ship

Ship ⇒ DK ⇒ DS ⇒ DK⇒ Ship

From Train to Ship

Train ⇒ DR ⇒ DS ⇒ DK ⇒ Ship

From Truck To Ship

Truck_Out ⇒ DS ⇒ DK⇒ Ship

The authors used a real case study of an Italian Port Terminal as reference in order to evaluate the current EIs and the EIs by considering new solutions allowing to improve port terminal sustainability:

- improvement of rail infrastructures

In particular the first scenario considers:

- Flow of 700'000 TEU
- Lower use of rail transportation (30% of the total flow)
- Heavy Fuel Ship Engine

Scenario_1			
Flow	700000	TEU/anno	TEU/anno
Interport	60%	to Truck	420000
Rail_Transportation	30%	to Train	210000
Transhipment	10%	to Feeder Ship	70000
Waiting Time at Gate	1	h	
Heavy Fuel			

The second scenario take into account:

- Flow of 700'000 TEU
- Increase Rail transportation (60% of the total flow)
- Low Sulfur Fuel Ship Engine

Scenario_2				
Flow	700000	TEU/anno		
Interport	30%	to Truck	210000	TEU/anno
Rail_Transportation	60%	to Train	420000	TEU/anno
Transhipment	10%	to Feeder Ship	70000	TEU/anno
Waiting Time at Gate	20	min	0.333333	h
Low Sulfur Fuel				

The Authors created the Conceptual Model by using the GreenLog Objects and implemented it in GreenLog Simulator by defining the general architecture based on the following critical elements:

- Ship_Arrival that represents the entrance operations in the port
- Transhipment to load containers from a ship to a ship
- Dock that refers to the dock operations
- Yard
- Rail Transportation
- Multimodal Terminal for representing containers to external truck

The different critical nodes are connected in order to represent the whole port terminal model:

The main characteristics for handling operations present in the terminal are summarized in the following table:

	Capability[kg]	Productivity	speed[m/s]	Hp	Number
Portainer	50000	25	0.75	470	4
Transtainer RTG	46000	25	2.2	750	3
Reach Stacker	46000	20	7	242	4
Truck 1_Out	45000	13	15	371	20
Transtainer RMG 1	50000	25	1	750	1
Transtainer RMG 2	50000	20	1	750	1

The authors model stochastic ships using for average reference vessel the following features:

- Average Capability 8000 TEU
- Average Length 332.0 m
- Average Width 43.2 m
- Maximum Draught 16.0 m

Figure 14. Ship of Reference

Concerning with EIs the authors focused this analysis on the following elements:

- Air emissions (CO, NOx, PM10)
- Power Consumption
- Tire Consumption
- Dust
- Noise
- Waste

In addition the model allowed to estimate the following KPIs:

Terminal throughput
Hour Productivity
Container Handling Costs
Year Profitability

The Emission Factors used in the model was set based on from European standards for Diesel Engine and from European Reports about Rail System Environmental Impacts [12] [27]:

Emission Factors for Represenative Diesel Engines		
CO Emissions Factor	1.5	g/kWh
NOx Emissions Factor	12.5	g/kWh
PM Emissions Factor	0.3	g/kWh

Emissions	Ship Heavy Fuel [g/kWh]	Ship Low Sulfur Fuel[g/kWh]
Nox	15.2	17.5
CO	0.9	0.69
CO2	691	676
SO2	9.5	0.26
PM	0.67	0.14

Average Rail Energy Consumption Analysis for European Trains	
German Trains	22.78 KWh/trainKm
French Trains	17.95 KWh/trainKm
Spanish Trains	16.58 KWh/trainKm
European Average Energy Consumption	**19.10 KWh/trainKm**

Rail Emissions for Diesel railway Locomotives	
Emission Power Specific g/kWh Fuel Specific - g/kg	
CO	1 - 10 5 - 40
HC	0.5 - 4.0 3 - 25
NOx	6 - 16 30 - 70
Particulate	0.2 - 1.2 1 - 6
SO2	0.2 - 2 1 - 10

By running on this scenario the Green Log Simulator it is possible to extract the following results summarized in the following Green Log reports and charts.

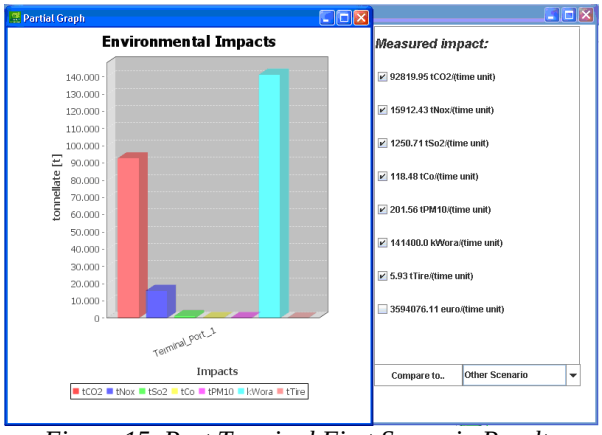


Figure 15. Port Terminal First Scenario Results

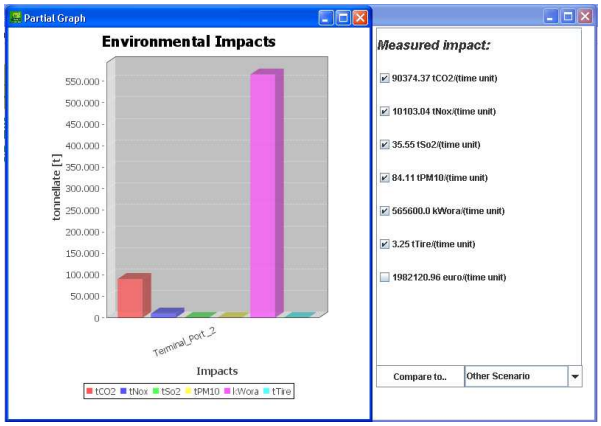


Figure 16. Port Terminal Second Scenario Results

From the analysis of the obtained data it emerge that second scenario confirms the possibility to guarantee high reduction of CO2 and SO2 emissions.
The first aspect could be correlated to the reduction of trucks waiting time at the gate and on the improvement of rail infrastructures by using electrical locomotives; the second one is related to the use of low sulphur fuel for ships in the second scenario.

On the other hand the electricity consumption increase in the second scenario due to the increasing use of electrical locomotive transportation.
Some comparisons are reported in the following diagrams.

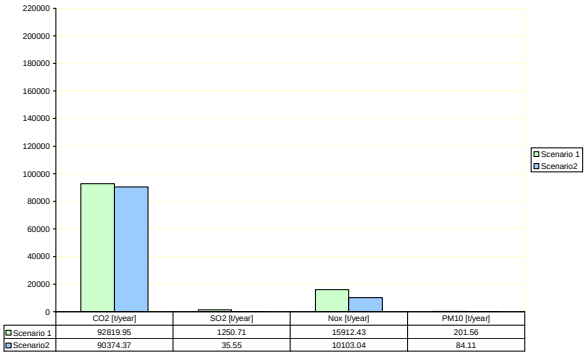


Figura 17. Air Emissions Comparison

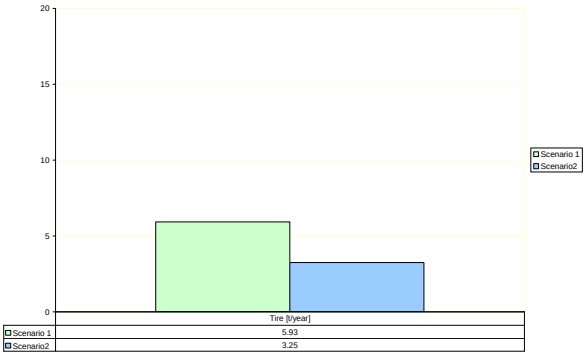


Figure 18. Tire Consumption Comparison

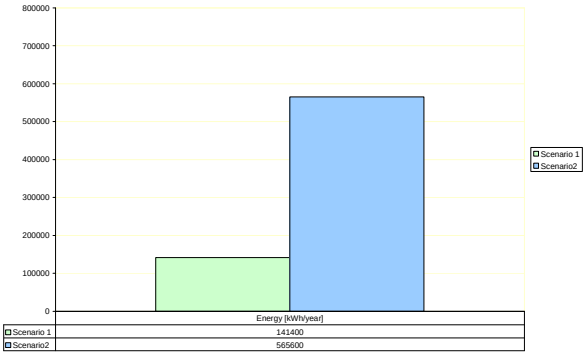


Figure 19. Power Consumption Comparison

5. CONCLUSIONS

The research proposes a model of a Port Terminal devoted to support its logistics, operational as well as environmental efficiency; in fact in order to analyze and evaluate Environmental Impacts related to these complex phenomena the use of simulation represent a strategic advantage able to guarantee good benefits; in fact this approach move qualitative greening concepts to quantitative results by running the simulator, so it become possible to analyze and to compare different solutions such as the use of low sulphur fuel instead heavy fuel or the use of electronic seal instead the mechanical one. The proposed results highlights the

relevance of modelling and simulation as support for EIs analysis in logistics and for decision making in term of strategies and solutions adoption for sustainability improvement in a Port Terminal. As matter of fact, the authors present GreenLog Simulator as decision support tool for Environmental Impacts Evaluation in different scenarios (maritime as well as terrain). The future development of these researches will be focusing on the evaluation of combined KPI able to provide an overview of different solutions in term of combined efficiency/cost/safety/quality and sustainability in complex logistics networks as well as in port operations

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