# Alternative Technologies for Controlling CO2 Emissions and Energy Costs Minimization in Manufacturing Processes

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***Abstract*—Provided that energy consumption goes together with CO2 emissions and high production costs, multinational companies seek perpetually to implement the best practices in an effort to satisfy customers not in terms of fair prices, quality and quantity delivered but also in terms of delivering products that respect environmental regulations. It seems that it is no longer optional for companies to opt for environmental practices, while having two major reasons to remain cost efficient and customer seductive: their production processes will no more tolerate waste in energy and their customers are consciously more than ever seeking eco-friendly products. In this paper, we conduct a cost analysis based on a comparison traditional with eco-friendly technologies in manufacturing detergent products based on different sources of energy.**

***Keywords*— CO2 emissions, Energy resources, Manufacturing Processes, SCG, NCV, GHG**

## 1. Introduction

TODAY'S manufacturing practices and processes are subject to perpetual changes and market constraints as the market regulations change and evolve over time, compelling companies facing factors that are blocking up their productivity development to naturally adjust or disappear.

Due to recent changes in competition and information, companies today are being forced to reconsider processes that have worked for decades. For firms in relatively slow-growth industries, lowering costs is essential to future success. In the light of a visit to detergent company that intended to lower costs and increase competitiveness, we have identified the transformation process as a potential area for significant cost reduction.

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Ideally, the findings could have important effects on the production process of detergent, not only in terms of cost reduction but(primarily cost of energy) but in terms of the reduction of CO2 emissions as well.

The present transformation processes that do not conform to environmental regulations, could potentially be outdated and have recently come under some criticism. Inefficiencies have been discovered and other inconsistencies are apparent. Emphasis is being placed on rethinking the transformation process in an effort to most efficiently produce and manufacture products that satisfy the eco-friendly requirements of customers, the governmental and the market regulations as well.

## 2. Objective and Problem Setting

The primary objective of this paper is to establish a current baseline of all costs involved in heat generation, when heat is generated from a boiler operating with the Butane gas, highlighting the portion of CO2 emitted in transportaion and production. Then, the baseline will be compared to an alternative biomass technology, using biomass energy sources in terms of energy value generated, CO2 emitted and costs expended, while highlighting the portion of transportation costs, production operations and maintenance costs, and inventory costs.

The following metrics will be used to measure the degree of objective achievement:

First, for biomass scenarios, we precise the costs of bioamss supply including cost of material per ton and delivery cost per ditance traveled and pet ton; the inventory costs and the costs of production per ton, including principally the per ton cost of the biomass dryer responsible for lowering the mositure content from biomass products to make it usable by the boiler, then cost of maintenance required to sustain the boiler including principally the cost of workforce responsable for reremoval of ash that is derived from biomass burned, and including equipement replacement as well.

Secondly, the analysis consists of the identification of potential scenarios for improvement by considering alternative biomass energy resources and their impact on cost efficiency and CO2 emission.

The target of our study is the detergent manufacturing process. The manufacturing station of detergent products is comprised mainly of mixer, spray tower and packing. The base powder is fashioned from various ingredients. The produced base powder is escalated at the expulsion of a spray tower, then, dry feeders intervene to add other ingredients.

After mixing, the detergent powder passes through a final sieve and metering stage. In the final step, the finished product is transferred into the packing operation before moving to the storage area.

It's essential for the scope clarification of this study, to point out that the spray drying tower is the major unit that consumes the highest amount of gas compared to other processes. A Butane gas boiler is used to preheat the furnace responsible for drying the detergent powder.

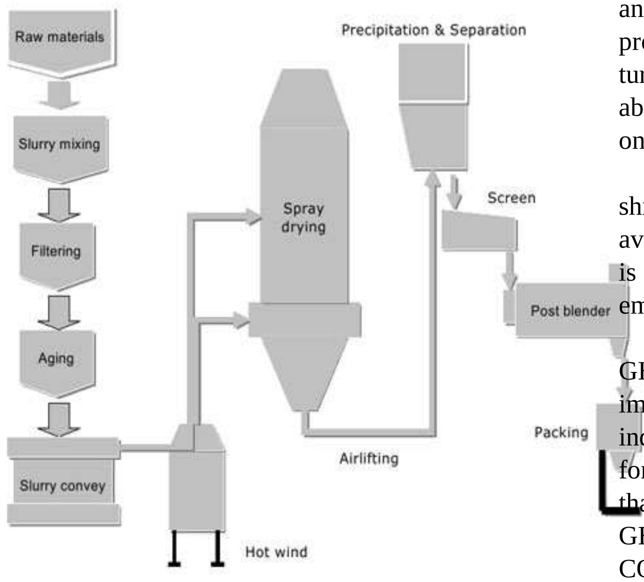



**Figure 1.** Detergent Manufacturing Process

The baseline represents the status quo which considers Butane as the only and main source of energy from which the boiler station of detergent manufacturing is sourced.

In this paper, we will explore the energy value and costs breakdown for the baseline scenario and compare it with the other scenarios touching the implementation of environmental technologies based on Biomass energy. In other words, we will examine the feasibility of using a biomass boiler that will preheat the furnace and keep the gas boiler as a backup system.

Biomass is a biodegradable organic substance coming from plants, animals and microorganisms and not an outcome of fossilized substances. Such as products, co-products, by-products and waste from agriculture, forestry and related industries, the organic solid waste in urban and industrial, as well as gas and liquid from the degradation of organic material biodegradable.

Biomass is considered as a renewable energy source derived from natural material and which can be converted either directly or indirectly into thermal, chemical or biochemical energies.

These are the different derivatives of Biomass:

"Biomass" / "Biofuel" / "Bioenergy" (FAO 2004)

Biomass sources : agricultural / forest / waste

Biofuel: solid / gas / liquid

Bioenergy: thermal / mechanical / electrical

Throughout time, a variety of Biomass technologies with different or comparative advantages and costs have been used. Dry biomass sources can be simply combusted to generate heat for industrial processes or space heating. Alternatively this heat can be used to drive a steam turbine which generates electricity. Combined heat and power (CHP) is the highly energy efficient process where the waste heat from the power turbine is used locally with a typical efficiency of about 70 to 80% for the large scale systems but only around 50% for the small scale ones.

In biomass technologies, we may consider wood ships fuel and olive cake and pits fuel as they are available in the context of the current study which is carried out in Morocco. The target of gas emissions is CO2 emissions.

CO2 has been chosen as measure of emission of GHG (Green House Gases), since it is the most important toxic gas tracked and monitored by most industrials and researches; they use it as an index for the other GHG emissions, as it has been proved that CO2 emission is highly correlated with other GHG emissions, showing an increase when the CO2 footprint is at its highest level.

To heat the water of the boiler, biomass sources need to be combusted. Combustion corresponds to the use of biomass to produce heat used locally only. The majority of combustion technologies used today are commercially proven and well established globally for many applications. Research and development today are essentially struggling to improve energy efficiency and reduce their environmental impact. Combustion systems for forest biomass are more complex than those operating with fossil fuels. The latter uses fuel with constant and known properties, established by standards, while forest biomass systems use a fuel which in many cases may have variable level of moisture, variable size and contain a certain percentage of contaminants.

For these reasons, combustion systems for forest biomass require careful integration of different components in order to obtain maximum performance. Installation of biomass boiler, as well as the back-up system should be determined by experts depending on the intended use.

The goal is to get the lowest energy cost possible by optimizing the supply of Biomass to the plant and the operations of the Biomass installation.

The tables below give us an idea about the costs and the calorific value of different sources of energy for an average 10% moisture content.

For other levels of moisture content, we assume that 10% decrease in moisture entails an approximate 0.6 kWh/kg increase in energy content.

**Table 1.** Comparison of energy costs for selected energy sources

| Fuel Type | Cost ($/unit) | Gross Cost ($/kWh) | Net Cost ($/kWh) |
|---|---|---|---|
| Electricity | 0,08 $/kWh | 0,080 | 0,080 |
| Ships | 70 $/ton | 0,025 | 0,033 |
| Olive cake | 80 $/ton | 0,035 | 0,050 |
| Wheat straw | 75 $/t | 0,030 | 0,045 |

Table II displays the average conversion of energy values to the same basis.

**Table 2.** Comparison of energy value for selected energy sources

| Fuel | Unit | MJ | KWh |
|---|---|---|---|
| Electricity | kWh | 3.6 | 1 |
| Wheat straw | Ton | 15 | 4.3 |
| Ships | Ton | 16.9 | 4.6 |
| Olive cake | Ton | 18.8 | 5.5 |

The energy sources are selected based on their availability in the Mediterranean region (the targeted zone in this study), and ordered from the lowest to the highest calorific value.

When low-cost biomass sources are available abundantly from a nearby location resulting in a reduced cost of delivery and transport, and when capital and maintenance costs are quite fair, biomass can be a very competitive heat option. However, if one or more components of the cost varies significantly, an in depth analysis should be conducted to state whether biomass energy-sourcing is a viable option that could be economically justified.

This report examines the biomass material cost of between $50 per ton for local wood and olive residues to $60 per ton for internationally traded residues. The cost of material might be high in case the biomass is collected from distant and decentralized locations and if storage is required before delivery.

The transportation cost, as known varies upon distance and load, it might be modest in case biomass load is transported over short distances, however, it increases if significant distances and loads are involved. If sourcing locations are decentralized it might prevent the benefit from the economies of scale in transport. For equal calorific values, more wet material is needed over dried material. The pre-treatment used in the drying process to lower moisture and then achieve higher energy densities can help reduce the quantity transported and by the same mean lower transportation costs. By doing so this would prevail over the loss in economies of scales due to sourcing decentralization.

The investment cost along with maintenance cost varies upon technology type.

The production cost in this paper refers to the drying cost, as 5% moisture level is what is sought by the furnace to reach the heat requirements.

This study attempts to produce heat for the furnace from biomass in the most economical way, it shows us how to make best tradeoffs between various biomass alternatives, using a biomass firing technology, in which the biomass being fired is used for producing steam required for heating the furnace only. Provided that the electrical energy could be generated from a steam-based turbine that could be annexed to the boiler, though useful, this energy is not really measured and tackled in this project. The assumption made is that the steam turbine generates the same quantity of electricity regardless of the type of biomass used in the process, thus the focus is made on heat generated only and not on electricity.

Lastly, the study draws a cost-based analysis of various biomass energy-sourcing with comparison to the Butane conventional energy-souring.

## 3. Literature Review

Recent literature showed that most researches start investigating on the apparent added value (mainly cost efficiency, social impact and CO2 emissions) of green supply chains (GSC) on companies in developing countries to facilitate the adoption of its philosophy and therefore to ease its implementation.

The concept of GSCM is relatively newer in developing countries. Recent literature found that still lack of researchers study on GSCM adoption and implementation based in developing countries.

So far, electricity and butane were the unique source of energy used in production processes of companies operating in developing countries. As the number of regulations increase, multinational companies with speed-growing rate and large market shares are the first actors to look for new technologies to preserve their competitiveness. Consequently, they are the first to introduce green practices in their operations and processes, giving this way a good example to follow for small companies with slow-growing rate. This rule is now evident in developing countries like Morocco while worships, conferences, research consortiums on green practices are increasing rapidly. In fact, in early 2012 Renault started adopting green practices by implementing a zero CO2 plant. Renault Morocco shows that the new Biomass technology implemented produces 18 MWh, and save 93% on CO2 emissions at a yearly basis.

The study carried out by Liu *et al.* (2011), confirmed that a company's environmental management abilities will be strongly enhanced by recurrent internal training of employees to increase its involvement in green supply chain management (GSCM) practices. Another research from China, carried out by Yan Li (2011), examined the implementation levels of GSCM practices and explored the performance measurement for GSCM. The findings demonstrated that GSCM was strongly balancing to other advanced management practices.

The study conducted in India by Diabat and Govindan (2011) identified the drivers influencing the implementation of GSCM and extracted 11 drivers collected through past literature: Certification of suppliers' environmental management system; environmental collaboration with suppliers; collaboration between product designers and suppliers to reduce and eliminate product environmental impacts; government regulation and legislation; green design; ISO 14001 certification; integrating quality environmental management into planning and operation process; reducing energy consumption; reusing and recycling materials and packaging, environmental collaboration with customers; and reverse logistics.

One study from Malaysia that has been carried out by Eltayeb and Zailani (2009) has identified the four key drivers or motivators to green supply chain initiatives: Regulations, customer requirements, expected business gains, and social responsibility.

Multiple authors analyzed the relationship between green supply chain initiatives and performance outcomes, like Walker *et al*. (2008), Sundarakani *et al.* (2010) , Zhu *et al.* (2008), Cruz (2008) , Beamen (1999), Azevedo *et al.* (2011).

For example, Walker *et al*. (2008) studied the drivers of environmentally friendly practices in the supply chains of public and private sector organizations, and the barriers these organizations face in implementing green SCM practices. Azevedo *et al.* (2011) investigated the relationships between green practices of SCM and supply chain performance. In the empirical study, they identify the most important green practices considered by managers, as well as the measures that are most widely used as means to evaluate the influence of green practices on supply chain performance. The developed model provided evidence as to which green practices have positive effects on quality, customer satisfaction and efficiency. It also identified the practices which have negative effects on supply chain performance.

Cruz (2008) developed a dynamic framework for the modeling and analysis of supply chain networks with corporate social responsibility through integrated environmental decision-making. Zhu *et al.* (2008) empirically investigated the construct of and the scale for evaluating green SCM practices implementation among manufacturers. Sundarakani *et al.* (2010) examined the carbon footprint across supply chains. The findings state that carbon emissions are accumulated across stages in a supply chain leading to a significant magnified threat.

According to Beamen (1999), manufacturing companies may achieve green supply chain by following the basic principles in ISO 14000. Azevedo *et al.* (2011) recommended the following Green practices: Environmental collaboration with suppliers, environmentally friendly purchasing practices, working with designers and suppliers to reduce and eliminate product environmental impact, minimizing waste, decrease the consumption of hazardous and toxic materials, ISO 14001 certification, reverse logistics, environmental collaboration with customers, environmentally friendly packaging, and working with customers to change product specifications.

## 4. Scenarios Analysis

As explained before, the current system for preheating the furnace uses a gas boiler, which consumes 190 tons per year of Butane. The gas boiler generates a large amount of CO2 emissions during combustion, in addition to the fact that it is costly in Morocco due to its non-availability and price fluctuations. The idea behind the use of vegetation waste is to replace the gas boiler with a biomass boiler that uses combustion to heat water; the resulting steam is then used to preheat the spray tower furnace.

The biomass found in the Mediterranean area is known for containing an important percentage of moisture. For this reason, the biomass used for preheating will be dehydrated using a biomass dryer to reduce the moisture content to a minimum. The

usage of the biomass dryer will facilitate the combustion, increase the efficiency of the biomass boiler, increase the steam production, and reduce CO2 emissions.
Our model presents a Customer Site (Factory boiler) which places a demand order for a fuel quantity from the Manufacturing Plant (Factory dryer). The raw materials are the biomass fuels purchased from different suppliers (Meknes, Tunisia, and Spain), they are dried using a biomass dryer to reduce their moisture content and increase their calorific value during combustion. There are 7 scenarios in total, one is the baseline or status quo and the others concern biomass fuels: Olive pits and Cake with different moisture percentages (10 and 15%) and from different suppliers (Meknes Morocco, and Tunisia), wood ships with different moisture contents (20% and 30%) from Spain.

The simulation aims at considering the CO2 emissions resulting from production processes. Using Supply Chain Guru the supply chain optimization tool, the green supply chain model is based on biomass energy and is to be compared to the regular model that does not include green considerations.

## 4.1. Scenario Description

### *4.1.1. Baseline Scenario Butane*

In the baseline we consider the minimization of total costs, including the operating costs, the inventory holding costs, and the cost of material. The objective function is subject to the constraints of heat demand satisfaction.

### *4.1.2. Scenario2: Olive Pits and Cake 10% M (Tunisia)*

In the scope of this paper, the target biomass energy is the olive cake since most countries in the Mediterranean region are cultivating olive. This scenario assumes olive pits with 10% moisture are purchased from Tunisia to be dehydrated to 5% Moisture. They are transported from Tunisia to Casablanca using ship. Olive pits and cake are available with large quantities in Tunisia and are therefore cheaper.

The moisture content is originally 15% but the supplier takes care of pre-drying the olive residues to reduce their moisture from 15% to 10%.

### *4.1.3. Scenario3: Olive Pits and Cake 15% M (Tunisia)*

Similar to scenario 2, the pits and cake are brought from Tunisia with 15% moisture. The onsite dehydration taken care by the manufacturer will result in a 5% moisture finished product.

### *4.1.4. Scenario4: Olive Pits and Cake 10% M (Meknes)*

The olive pits and cake with 10% moisture are purchased from Meknes and transported to Casablanca by truck. They will be dehydrated at the factory to produce a 5% moisture finished product.

### *4.1.5. Scenario5: Olive Pits and Cake 15% M (Meknes)*

Similar to scenario 4, the biomass has 15% moisture, and will decrease to attain 5%.

### *4.1.6. Scenario6: Wood 20% M*

In this scenario, we consider the usage of wood ships for biomass combustion. It would be shipped from Spain for its availability. After dehydration processing, the finished product is a 5% moisture wood ships. Pre-drying from 30% to 20% taken care by the supplier is assumed in this scenario.

### *4.1.7. Scenario7: Wood 30% M*

Similar to scenario 6, using a 30% moisture content.

## 4.2. Scenarios Data

### *4.2.1. Products*

This SCG table represents the finished product for each scenario which represents the final dehydrated biomass fuels consumed. This table contains the name of the finished product as well as its value (raw material cost in Euros), in addition to the Butane which is being compared to biomass fuels.
The Net Calorific Value represents the energy value of the fuel per ton. The Price of the finished products is represented by the NCV (in MJ/ton) and divided by 10 for model purposes. The evaluation is carried out through the comparison of the costs (in Euros) and revenues (in MJ/ton /10); the profit will be ignored.

| Name | Value | Price |
|---|---|---|
| Olive P&C 5%M (from 10% Meknes) | 70 | 220 |
| Mix 7%M (from 20%) | 65 | 205 |
| Butane | 630 | 495.1 |
| Olive P&C 5%M (from 15% Meknes) | 60 | 220 |
| Wood 5%M (from 20%) | 60 | 174.53 |
| Olive P&C 5%M (from 10% Tunisia) | 50 | 220 |
| Wood 5%M (from 30%) | 50 | 174.53 |
| Olive P&C 5%M (from 15% Tunisia) | 40 | 220 |

**Figure 2.** Products table in SCG

### 4.2.2. *Demand*

The gas and biomass boilers require 2 MWh and function 6 days a week nonstop. The following table represents the demand for feedstock (in tons per month) to supply the energy required. The quantity shown in the table represents the demand for raw material feedstock and not the finished products.

| Product Name | Site Name | Quantity | Occurrences | Time Between Orders |
|---|---|---|---|---|
| Olive P&C 5%M (from 15% Tunisia) | Boiler (CZ) | 244 | 12 | 4 WK |
| Olive P&C 5%M (from 10% Tunisia) | Boiler (CZ) | 219 | 12 | 4 WK |
| Wood 5%M (from 30%) | Boiler (CZ) | 341 | 12 | 4 WK |
| Wood 5%M (from 20%) | Boiler (CZ) | 288 | 12 | 4 WK |
| Olive P&C 5%M (from 15% Meknes) | Boiler (CZ) | 244 | 12 | 4 WK |
| Olive P&C 5%M (from 10% Meknes) | Boiler (CZ) | 219 | 12 | 4 WK |
| Butane | Boiler (CZ) | 84 | 12 | 4 WK |

**Figure 3.** Demand table in SCG

### 4.2.3. *Production costs*

Production costs are inserted in a SCG sourcing policies table. They include cost of the raw materials (biomass fuels) and the drying process which add up to give the average unit cost (€/t).
Production Cost = Cost of Raw Material + Cost of Drying
For each product, two sourcing policies are required:

- Single Source policy: Ordering the product from customer to manufacturer. In this model, ordering does not incur a cost and therefore, its average unit cost is set to 0.
- Make policy: Ordering the product demanded by the customer inside the factory. In other words, its average unit cost represents the production cost.

The following table represents the sourcing policies in SCG:

| Source Name | Site Name | Product Name | Sourcing Policy | Avg Unit Cost |
|---|---|---|---|---|
| Factory | Boiler (CZ) | Olive P&C 5%M (from 15% Meknes) | Single Source | 0 |
| Factory | Boiler (CZ) | Olive P&C 5%M (from 10% Tunisia) | Single Source | 0 |
| Factory | Boiler (CZ) | Wood 5%M (from 30%) | Single Source | 0 |
| Factory | Boiler (CZ) | Wood 5%M (from 20%) | Single Source | 0 |
| Factory | Boiler (CZ) | Olive P&C 5%M (from 10% Meknes) | Single Source | 0 |
| Factory | Boiler (CZ) | Mix 7%M (from 20%) | Make | 70 |
| | Factory | Olive P&C 5%M (from 15% Meknes) | Make | 69 |
| | Factory | Wood 5%M (from 30%) | Make | 55 |
| | Factory | Wood 5%M (from 20%) | Make | 70 |
| | Factory | Olive P&C 5%M (from 10% Meknes) | Make | 77 |
| | Factory | Olive P&C 5%M (from 10% Tunisia) | Make | 57 |
| Factory | Boiler (CZ) | Butane | Single Source | 0 |
| | Factory | Butane | Make | 630 |
| Factory | Boiler (CZ) | Olive P&C 5%M (from 15% Tunisia) | Single Source | 0 |
| | Factory | Olive P&C 5%M (from 15% Tunisia) | Make | 49 |

**Figure 4.** Sourcing policies table in SCG

### 4.2.4. *CO2 emissions*

The idea behind using biomass as fuel for the factory boiler is to reduce CO2 emissions that are otherwise released by the combustion of gas. During their life, biomass absorbs CO2 to grow through photosynthesis; and that CO2 amount is returned back to the atmosphere when biomass is combusted. This means that the combustion of biomass does not increase the amount of CO2 in the atmosphere and can be summarized to be 0. For the latter reason, we assume that CO2 emissions related to the combustion of biomass fuels are 0.
Total CO2 emissions are computed differently for Butane and biomass fuels. For biomass fuels, CO2 emissions are calculated from the transportation shipments only.
For Butane, CO2 emissions include those of combustion and transportation. They are computed as following:

- CO2 emissions of Butane Combustion = Butane default CO2 emission factor * Butane Net Calorific Value
- Total CO2 emissions for Butane = Combustion CO2 + Transportation CO2

**Table 3.** Butane CO2 emissions calculations

| Butane | | | | |
|---|---|---|---|---|
| Net Calorific Value (MWh/ton) | CO2 emission factor (kgCO2/MWh) | Combustion CO2 emissions (ton CO2/ton) | transportation CO2 emissions (ton CO2/ton) | Total CO2 emissions of Butane (ton CO2/ton) |
| 13.752 | 222.35 | 3.058 | 0.59 | 3.648 |

CO2 emissions for transportation are based on the CO2 standards of DEFRA. Supply Chain Guru provides a field that computes automatically the CO2 emissions using the latter standards for road and water shipment. CO2 basis is a quantity-distance, therefore the CO2 emission quantity is set at ton per unit of distance.

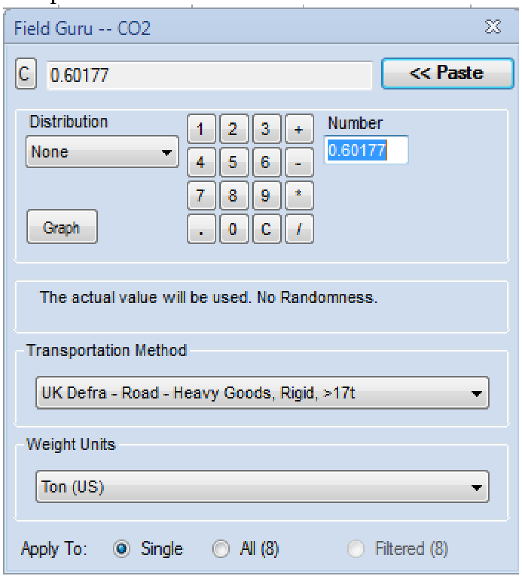



**Figure 5.** CO2 emissions for Transportation using Defra

### 4.2.5. *Transportation costs*

For supply Chain Guru, it is assumed that the finished products (dehydrated biomass fuels) are to be shipped. However, we have adapted the model to our needs and considered the raw materials to be shipped by inserting the demand for raw materials in their respective finished product demand cell. This will enable us to obtain the cost of transporting the biomass feedstock to the boiler.

The transportation cost depicts the cost of ship or truck shipment including the distance traveled; it depends on the quantity (tonnage) only. It is calculated as following:

Average Unit transportation cost (€/ton) = Average cost (€/ton/km)* Distance (km).

The following table represents the calculation of unit transportation cost:

**Table 4.** Unit transportation cost calculations

| Supplier | Product | Average cost (€/ton/km) | Distance and mean | Unit transportation cost (€/ton) |
|---|---|---|---|---|
| **Meknes** | Olive Pits and Cake | 0.036 | 260 km Truck | 9.36 |
| **Tunisia** | Olive Pits and Cake | 0.015 | 2000 km Ship | 30 |
| **Spain** | Wood | 0.0465 | 430 km Ship | 20 |

### 4.2.6. *Inventory costs*

The metric for calculating inventory is the inventory carrying cost, which represents the cost percentage for holding inventory of specified product at the factory site during the period of the optimization. We also specify the safety stock to represents ¾ of the demand, since availability of biomass is subject to uncertainty related to weather conditions and price fluctuations. The inventory carrying cost is 20% for biomass and 30% for Butane. The following table represents the inventory policies table in SCG:

| Site Name | Product Name | Review Per | Capacit | Inv Carrying | Safety Stock | Product Valu |
|---|---|---|---|---|---|---|
| Factory | Olive P&C 5%M (from 10% Meknes | Continuous | Quantity | 20 | 164.0715 | 70 |
| Factory | Olive P&C 5%M (from 10% Tunisia) | Continuous | Quantity | 20 | 164.0715 | 50 |
| Factory | Olive P&C 5%M (from 15% Meknes | Continuous | Quantity | 20 | 182.973 | 60 |
| Factory | Olive P&C 5%M (from 15% Tunisia) | Continuous | Quantity | 20 | 182.973 | 40 |
| Factory | Wood 5%M (from 20%) | Continuous | Quantity | 20 | 216 | 60 |
| Factory | Wood 5%M (from 30%) | Continuous | Quantity | 20 | 255.018 | 50 |
| Factory | Butane | Continuous | Quantity | 30 | 62.82 | 630 |

**Figure 6.** Inventory policies table

## 5. Statistical Results

### 5.1. Supply Chain Guru

Supply Chain Guru is a multiple time period modeling tool recognized as the leading

Supply Chain Design software application in the world today as it allows the possibility to do both optimization and simulation of supply chain network operations. As well as providing detailed reports on sites, flows and costs, the powerful map-based graphics within Supply Chain Guru, it allows an easier understanding of exactly what is happening within a logistics network by providing visualizers, maps, reports, and flows tables.

This software contains a MILP solver, which gives a true mathematical optimization of the problem at hand. Moreover, the solver also takes into account specific user-defined constraints to the network definition and cost models, such as:

- The capacities of sites, either in total or at product level
- The minimum flow through sites and lanes, either in total or at product level
- Whether sites can receive supply from multiple or single sources.
- The maximum emissions allowed

The user interface of Supply Chain Guru is very friendly and facilitates the navigation and the entry of data and constraints.

The plus of Supply Chain Guru (SCG) is that it can support an analysis of the Greenhouse gases emissions within the network. Emissions can be described either for sites, or for particular products at sites, in the same way as costs (taxes). Emissions at plants can be used to illustrate the impact of manufacturing and when applied to lanes will show the impact of transport. The system can be set up to:

- calculate the emissions of the current supply chain
- re-design the supply chain to minimize emissions
- re-design the supply chain to minimize costs with a defined target in CO2 emissions

Supply Chain turned out to be the perfect tool to opt.

Analysis of Data from GURU

To enter the baseline model and use Supply Chain Guru to optimize it, it was assumed that sites use one technology which is electricity-based, that all transformation operations are using the same type of energy electricity.

SCG enables to break down the model to be optimized into three major components: structure, costs and constraints. The structure includes all data related to sites of the network, products, demand, inventory policies, sourcing policies, transportation policies.

For costs, the SCG model groups production, inventory and transportation costs. Amongst a long list of constraints SCG enables to limit CO2 emissions by filling the field of CO2 emissions in the transportation policies, production and sourcing policies, since we look at emissions on production processes the focus will be made on them only.

The Max Carbon Footprint defines the maximum carbon footprint allowed in the model.

This is enforced by solving the model with this number as a hard constraint on output. The column with "Enforce Max Carbon Footprint" defines whether or not the Max Carbon Footprint value is used as a hard constraint. If it is left blank or set to No, the constraint is excluded from the mixed integer linear program used to optimize the model. In addition, the option to optimize Carbon Offset determines whether or not the number of carbon offsets needed for purchase should be included in the objective function of the network design optimization, and since there is no offsetting in the model of the project, we leave all the related variables set to zero. Finally, the Carbon Cost represents cost per unit of CO2 in the model. This field is used to model carbon taxation and other penalties for carbon emissions.

Once all these elements entered, Guru provides the possibility to view a representation of the network.

As far as the optimization is concerned, it is important in the options to specify the type of the objective function: costs minimization or profit maximization and to choose the output format, methods to use and constraints applied to the model. For the model of the green supply chain, the carbon constraints box is to be checked which is not the case for the regular model (Figure 2).

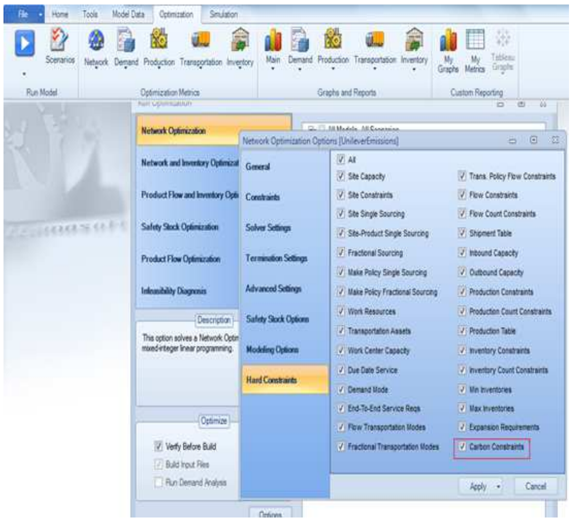


Figure 2. Models' Constraints

When the optimization is successful and no errors are displayed, and optimization status window is then generated with details about the problem size, the solution status, the detailed history of the optimization and a progress graph. In the sidebar of the optimization output, it is possible to get flows from different sites, summaries for customers and inventories as well as graphs for the operating costs and revenue by customer and by product.

As part of the output, it is possible to generate a summary of the network that summarizes all costs, revenue and carbon footprint of the whole network.

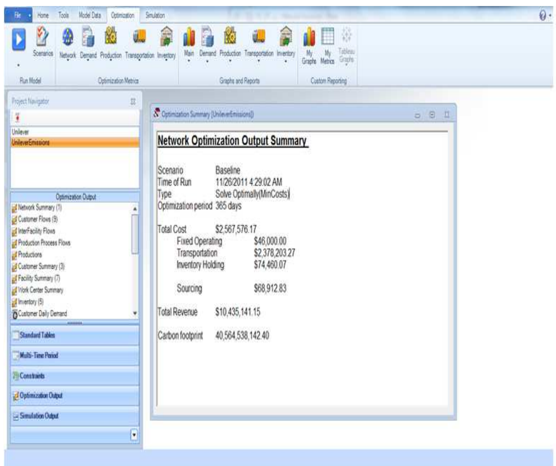


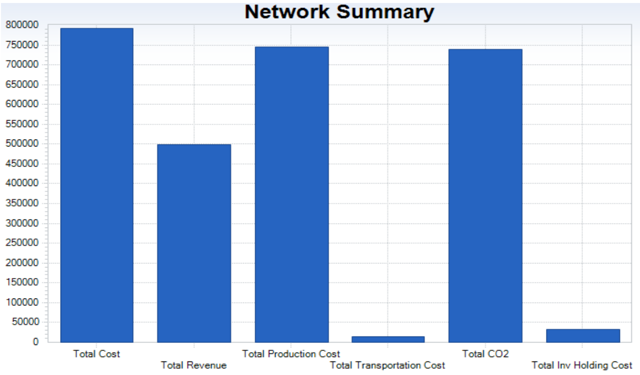
Figure 3. Optimization Window

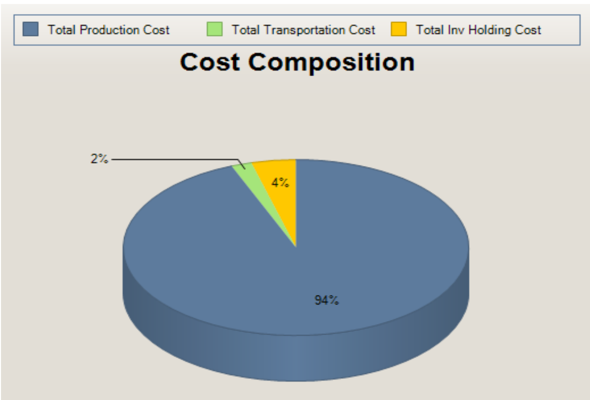
## 5.2. Scenario Results

### *5.2.1. Baseline Scenario Butane*

**Network Optimization Output Summary**

| | | |
|---|---|---|
| Scenario | Baseline | |
| Time of Run | 3/18/2013 12:03:36 AM | |
| Type | Solve Optimally(MaxProfit) | |
| Optimization period | 365 days | |
| Total Cost | €792,324.50 | |
| Production | | €744,336.47 |
| Transportation | | €15,120.00 |
| Inventory Holding | | €32,868.03 |
| Total Revenue | €499,060.80 | |
| Profit | €-293,263.70 | |
| Carbon footprint | 738,847.00 | |

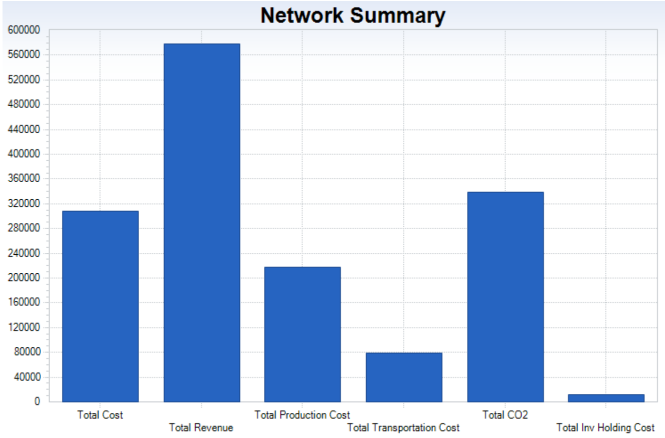


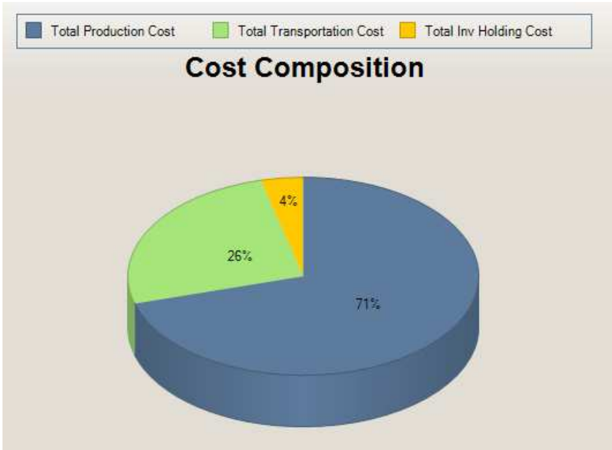




### *5.2.2. Scenario2: Olive Pits and Cake 10% M (Tunisia)*

**Network Optimization Output Summary**

| | | |
|---|---|---|
| Scenario | Baseline | |
| Time of Run | 3/17/2013 11:26:13 PM | |
| Type | Solve Optimally(MaxProfit) | |
| Optimization period | 365 days | |
| Total Cost | €307,893.18 | |
| Production | | €217,130.94 |
| Transportation | | €78,840.00 |
| Inventory Holding | | €11,922.24 |
| Total Revenue | €578,160.00 | |
| Profit | €270,266.82 | |
| Carbon footprint | 338,276.16 | |

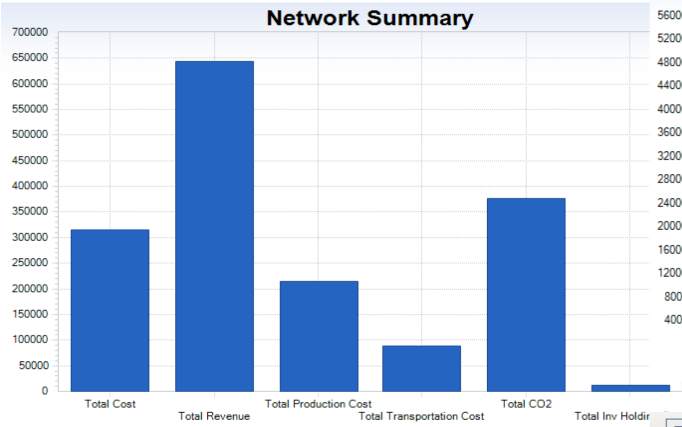


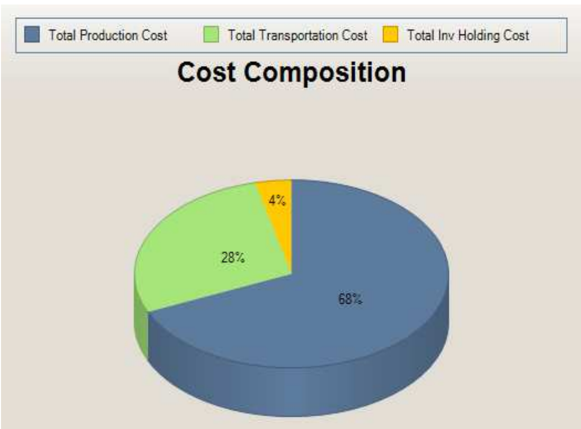



### *5.2.3. Scenario3: Olive Pits and Cake 15% M (Tunisia)*

**Network Optimization Output Summary**

| | | |
|---|---|---|
| Scenario | Baseline | |
| Time of Run | 3/17/2013 11:36:27 PM | |
| Type | Solve Optimally(MaxProfit) | |
| Optimization period | 365 days | |
| Total Cost | €315,073.51 | |
| Production | | €215,393.92 |
| Transportation | | €87,840.00 |
| Inventory Holding | | €11,839.59 |
| Total Revenue | €644,160.00 | |
| Profit | €329,086.49 | |
| Carbon footprint | 376,892.16 | |

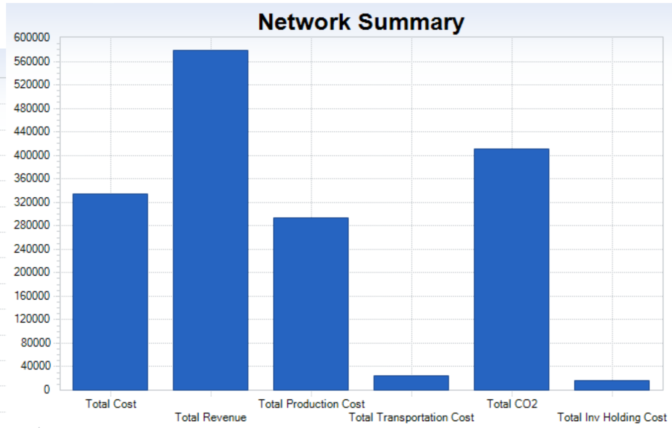


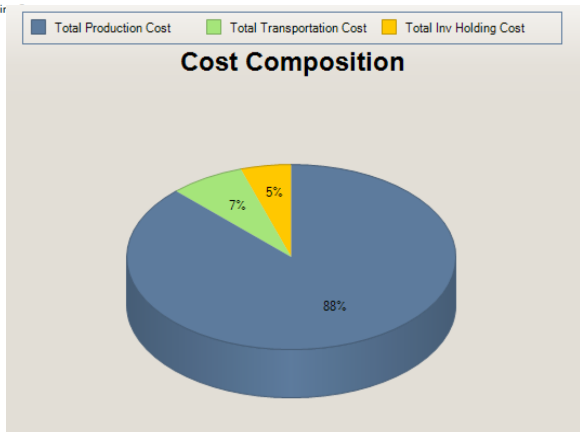




### *5.2.4. Scenario4: Olive Pits and Cake 10% M (Meknes)*

**Network Optimization Output Summary**

| | | |
|---|---|---|
| Scenario | Baseline | |
| Time of Run | 3/17/2013 11:50:16 PM | |
| Type | Solve Optimally(MaxProfit) | |
| Optimization period | 365 days | |
| Total Cost | €334,473.58 | |
| Production | | €293,317.24 |
| Transportation | | €24,598.08 |
| Inventory Holding | | €16,558.26 |
| Total Revenue | €578,160.00 | |
| Profit | €243,686.42 | |
| Carbon footprint | 411,177.41 | |

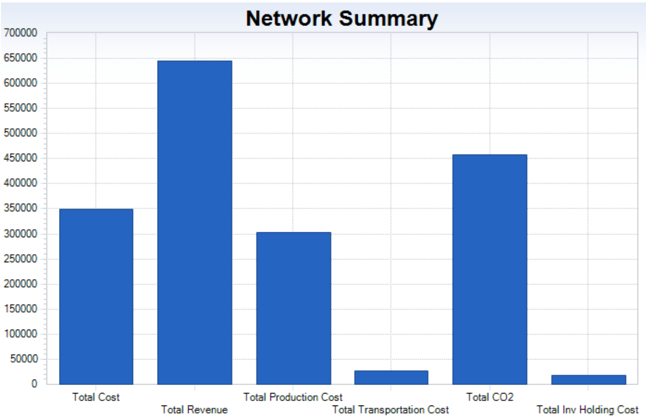


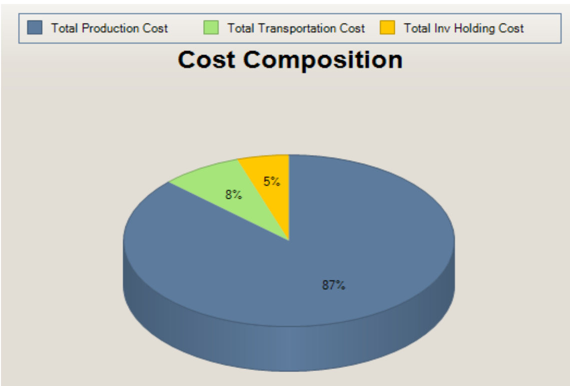



### 5.2.5. *Scenario5: Olive Pits and Cake 15% M (Meknes)*

**Network Optimization Output Summary**

| | | |
|---|---|---|
| Scenario | Baseline | |
| Time of Run | 3/17/2013 11:56:38 PM | |
| Type | Solve Optimally(MaxProfit) | |
| Optimization period | 365 days | |
| Total Cost | €348,348.38 | |
| Production | | €303,309.81 |
| Transportation | | €27,406.08 |
| Inventory Holding | | €17,632.49 |
| Total Revenue | €644,160.00 | |
| Profit | €295,811.62 | |
| Carbon footprint | 458,115.47 | |

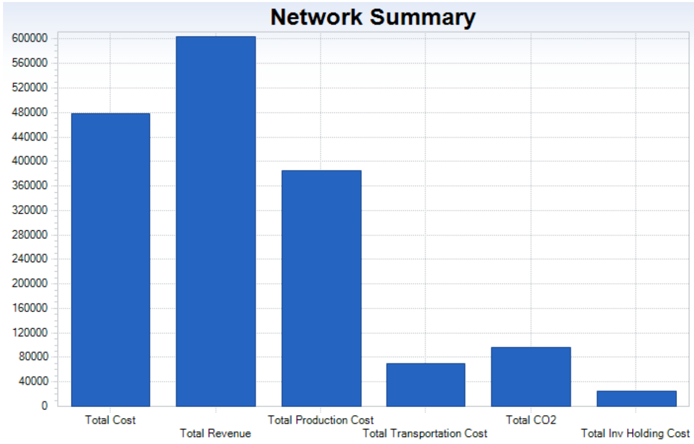


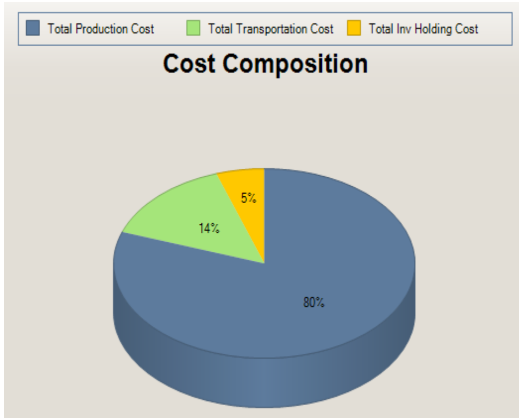




### 5.2.6. *Scenario6: Wood 20% M*

**Network Optimization Output Summary**

| | | |
|---|---|---|
| Scenario | Baseline | |
| Time of Run | 3/18/2013 12:09:46 AM | |
| Type | Solve Optimally(MaxProfit) | |
| Optimization period | 365 days | |
| Total Cost | €478,782.96 | |
| Production | | €385,083.62 |
| Transportation | | €69,120.00 |
| Inventory Holding | | €24,579.35 |
| Total Revenue | €603,175.68 | |
| Profit | €124,392.72 | |
| Carbon footprint | 95,644.11 | |

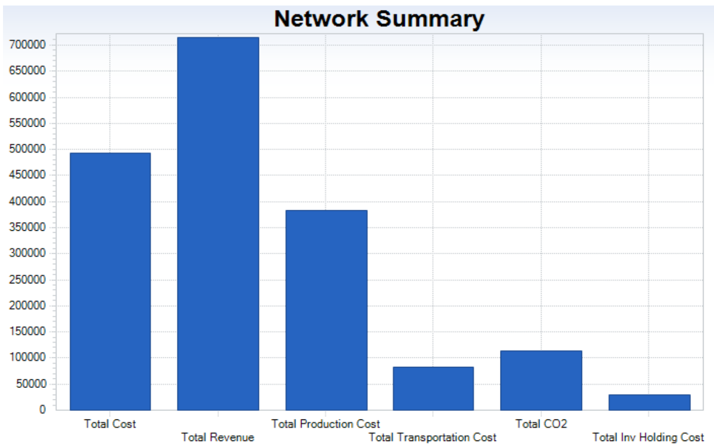


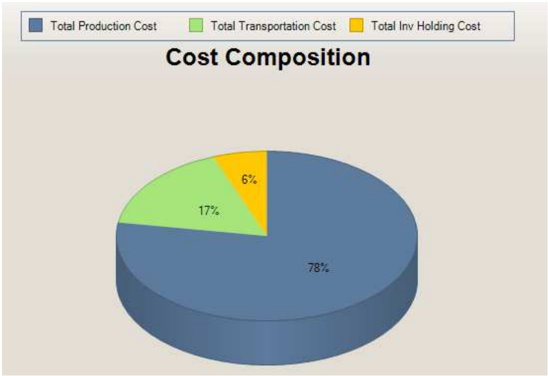




### 5.2.7. *Scenario7: Wood 30% M*

**Network Optimization Output Summary**

| | | |
|---|---|---|
| Scenario | Baseline | |
| Time of Run | 3/18/2013 12:17:41 AM | |
| Type | Solve Optimally(MaxProfit) | |
| Optimization period | 365 days | |
| Total Cost | €492,771.28 | |
| Production | | €382,304.80 |
| Transportation | | €81,840.00 |
| Inventory Holding | | €28,626.48 |
| Total Revenue | €714,176.76 | |
| Profit | €221,405.48 | |
| Carbon footprint | 113,245.28 | |






# 6. Conclusion

## 6.1. Comparison Table

The table below summarizes the statistical results shown in the previous section. It contains the total cost breakdown of each scenario including total production, transportation, inventory holding, total cost, total revenues, and total CO2 emissions. The highest and lowest values for each column are colored in red and green respectively.

| Scenarios | Total production Cost (Euros) | Transpo-rtation Cost (Euros) | Inventory Holding Costs (Euros) | Total Costs (Euros) | Total Revenues (NCV/10 in MJ/ton) | CO2 emissions (tonCO2/ ton) |
|---|---|---|---|---|---|---|
| 1st: Butane | 635040 | 15120 | 32868.03 | 792324.50 | 499060,80 | 738316,66 |
| 2nd : Tunisia 10% | 149796 | 78840 | 11922.24 | 307893.18 | 578160 | 338276,16 |
| 3rd : Tunisia 15% | 143472 | 87840 | 11839.59 | 315073.51 | 644160 | 376892;16 |
| 4th : Meknes 10% | 202356 | 24598,08 | 16558.26 | 334473.58 | 578160 | 411177,41 |
| 5th : Meknes 15% | 202032 | 27406,08 | 17632.49 | 348348.38 | 644160 | 458115,47 |
| 6th : Wood 20% | 241920 | 69120 | 24579.35 | 478782.96 | 603175,68 | 95644,11 |
| 7th : Wood 30% | 225060 | 81840 | 28626.48 | 492771.28 | 714176,76 | 113245,28 |

**Figure 7:** Scenario Cost Comparison Table

As shown in the comparison table, the 7th scenario involving 30%M Wood provides the minimum CO2 emissions with 95644.11 ton/year, while Butane generates the maximum amount with 738316.66 ton/year. The scenario showing the lowest total cost amount is the 2nd: Pits and Cake 10%M from Tunisia with 307893.18 as opposed to Butane with 792324.50 Euros/year.

## 6.2. Cost Composition Comparison

The pie charts of cost composition include total production cost, total transportation cost, and total inventory holding cost. For all scenarios, production costs represent the highest portion of the total costs ranging from 68% to 94%. Total transportation costs represent the second important portion of total costs for the six biomass scenarios ranging from 7% to 28%; except for Butane for which transportation represents 2% and inventory holding costs 6%. At last, Inventory holding costs are the last portion in biomass scenarios ranging from 4% to 6%. These pie charts show that production costs represents the highest costs incurred in the biomass boiler project followed by transportation and then inventory holding costs.

## 6.3. Investment and Maintenance Costs

We have analyzed the different costs related to production, transportation and inventory concerning the usage of a biomass boiler. However, other costs are added to the biomass scenarios such as the investment cost including the equipment cost (biomass dryer and biomass boiler), and fixed/variable operations and maintenance costs summarized. Fixed O&M costs include staffing, planned maintenance, intended equipment replacement, and insurance. Variable costs include other dealing with other fuels, ash removal, unscheduled maintenance, and unplanned equipment replacement.

**Table 5.** Equipment Costs

| Equipment | Initial Investment (Euros) | Fixed O&M | Variable O&M |
|---|---|---|---|
| Biomass Boiler | 226,086.95 | 3.2 – 4.2<br>3 – 6<br>(% of investment cost) | 2.94–3.64<br>(Euros/ MWh) |
| Biomass Dryer | 270,839.22 | 7.97 (Euros/ton) | |
| Total | 496,926.17 | - | |

*Sources:* S. Mani, S. Sokhansanj, X. Bi, A. Turhollow, (2006)
Irena, (June 2012)

## 6.4. Savings and best scenario

The current baseline scenario shows that the total costs for the gas boiler are 792,351.50 Euros/year and 738,316.66 tonCO2/ton. The lowest costs scenario is the 2nd one with 307893.18 Euros/year and CO2 emissions of 338,276.16 tonCO2/ton. The savings on costs if choosing the 2nd scenario are 54034.84 Euros/year. CO2 emissions will be reduced by 400,040.5 tonCO2/ton. This would represent the best case scenario if we discard the international issues involved in the purchased and transporting the olive pits and cake from Tunisia. However, it is important to recognize that other elements such as the taxes involved in purchasing foreign merchandise and the risks involved during transportation from one country to another. Having considered the latter issues, the 4th scenario with 10%M Olive pits and Cake from Meknes represents a second best scenario which does not include cross-border issues. This scenario is safer since it does not involve long distance transportation risks, and provides saving of 457850.92 Euros in total costs and 327139.25 tonCO2/ton in total emissions.

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