



Ecological Footprint as a sustainability indicator to analyze energy consumption in a Portuguese textile facility

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Abstract

The main objective of this paper is to apply Ecological Footprint methodology as a tool to analyze the Portuguese textile industry. This analysis is related to energy and resources consumption in dyeing, printing and finishing processes. It also includes identification of mitigation measures to increase energy efficiency, promoting at the same time the reduction of CO₂ emissions and consequently the decrease in industry's Ecological Footprint. Moreover, the analysis presents the Ecological Footprint reduction potential for each mitigation option proposed for an important textile facility located in the North Region of Portugal, used as a case study in this work. The results for the case study showed that the total Ecological Footprint accounted, for the year 2016, summed up to 4890 gha. Furthermore, the energy category corresponds to more than 50% of the total Ecological Footprint estimation, and natural gas was the most required fuel for the processes. The calculation of the Ecological Footprint in the textile facilities can be used as a tool to analyze the processes' energy efficiency and to quantify the global impact of the implementation of mitigation measures in the energy field. The result is an indicator shown in a common unit, gha (global hectare) and it can be easily used to compare energy-intensive processes and industrial sectors. In addition, it can be used to analyze how each sector can impact the country's total demand for resources.

Keywords Ecological Footprint · Textile facility · Sustainability indicator

Introduction

In 2016, Portugal consumed about 20 Mtoe, divided in oil (43%), natural gas (20%), coal (14%), electricity (10%) and biomass (13%) [1]. Moreover, in the same year, Portugal was the seventh most energy-dependent country in the European Union (EU) [1]. Only 28% (6 Mtoe) of the primary energy consumed in Portugal was produced internally [1, 2]. The Portuguese industrial sector consumes about 30% of the total energy, which is more energy than the total produced in the country [3]. In the case of the textile and clothing industry, the consumption reaches 6% of the industrial consumption. Thus, it becomes crucial to implement plans for energy efficiency in this sector, reducing consumption to move towards a more sustainable environment and reducing the country's dependence on energy imports. Portugal is aligned with the

European Energy Efficiency Directive (2012/27/EU) and has a target for 2020 to reduce by 26% total energy consumption from 2012 projections [4]. The industry sector alone should reduce 34,500 toe per year from 2016 to 2020 [4].

In order to analyze the sector and propose energy efficiency measures in these processes, this work suggests the use of the Ecological Footprint (EF) methodology as a tool to study the energy consumption. A “footprint” is a quantitative measurement describing the appropriation of natural resources by humans [5]. It describes how human activities can impose different types of burdens and impacts on global sustainability [6]. Ecological Footprint is defined as a measurement of the human demand for land and water areas, and compares the human consumption of resources and absorption of waste with the Earth's ecological capacity to regenerate [7–9]. The EF provides an aggregated assessment of multiple anthropogenic pressures [10]. The method aims at determining the degree of sustainability of activities and regions/countries [11, 12]. The EF is both an accounting method and an aggregate indicator. The accounting method converts the flows of energy to and from a specific activity into a corresponding land area that is required to support these flows [13–15]. The method

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considers different types of land categories such as, built up land, fishing-ground, forest land, grazing land, fossil land, arable land [14]. Ecological Footprint can be used to analyze industry sectors, specifically, the textile sector [16–19]. Moreover, it allows to quantify globally the sustainability performance of this type of facility [16–20]. This specific characteristic differs this indicator from others already established and often used by researchers in the field (i.e. indicators used in GRI Reports and Greenscope Reports). These indicators demand great amount of technical data, that may be not available, and its results require scientific specialists know-how to be analyzed and understood [21, 22].

The main objective of this paper is to apply EF methodology as a tool to analyze the Portuguese textile industry. This analysis is related to energy and resources consumption in dyeing, printing and finishing processes. It also includes identification of mitigation options to increase energy efficiency, promoting at the same time the reduction of CO₂ emissions and consequently the decrease in industry's EF. Moreover, the analysis presents the EF reduction potential for each mitigation option proposed for an important textile facility located in the North Region of Portugal, used as a case study in this work. The scientific literature cited in the present paper, showed methodologies and observations that should be taken into account when applying Ecological Footprint methodologies, but it did not present the impact of implementation of measures for increasing energy efficiency in textile facilities. It is worth mentioning that there is a lack of analysis in the scientific literature related to applying Ecological Footprint methodologies to the Portuguese textile sector and to the proposal of specific mitigation alternatives to reduce energy consumption, at the same time, and it is covered by this paper.

A textile facility

A textile facility can incorporate different processes such as weaving, dyeing, printing and finishing in the same unit or in separate ones, which results in products of high quality. Weaving is a method of textile production in which two distinct sets of yarns or threads are interlaced at right angles to form a fabric or cloth. Similar methods are knitting, felting, and braiding or plaiting. The longitudinal threads are called the warp and the lateral threads are the weft or filling [23]. In the case of dyeing, it promotes coloring to the fabrics and various types of dyes are added to the mesh in order to obtain the desired color. These operations are carried out in aqueous solutions, at temperatures between 20 and 130 °C. The printing process consists of transferring a colored material to the using a frame surface. After printing, it is necessary to dry to avoid spreading the material. The fixation can be done by vaporization or thermofixation [23]. After going through the stages of dyeing

and/or printing, the meshes are sent to the finishing section. As already mentioned, depending on the purpose of the produced fabric, it can go through several stages of finishing inside the factory, always ending up in the drying machinery.

These processes allow the fabric to have the desired color, texture and dimensional stability, as well as the uniformity of these properties. In these sections, the mesh runs through a variety of chemical and mechanical processes. Depending on the purpose of the mesh produced, it can be processed in all three units such as dyeing, printing and finishing, or just one of these, with all meshes going through the finishing section. Textile companies' processes, concerning energy consumption, require mostly natural gas, electricity and steam. In addition, these companies can use a small amount of propane gas, and diesel, for the transportation fleet [9, 23, 24].

As mentioned before, the textile sector is an energy-intensive industry and must be analyzed in order to reduce its consumption and look towards a more sustainable way of producing high quality fabrics. The following sections presents the methodology for Ecological Footprint estimation in an organization and it is applied to a case study (a real textile facility in Portugal).

Ecological Footprint estimation

The total EF estimation should consider all resources (materials, water, energy, waste) that are part of a process or an organization. In the case of a textile facility, all accounted inputs and outputs, which are present in these processes, can be divided into three main categories: resources (water and materials), energy and waste. All inputs and outputs concerning the processes/organizations should appear in an inventory table, indicating each input/output and the amounts consumed/used [16–20, 25].

Each footprint category is calculated based on following equations, which are divided in several categories. The Resources Footprint, calculated by Eq. (1) is given by [9, 14]:

$$F_{\text{resources}} (\text{gha}) = \sum (R_i / \text{NP}_i) * \text{EF}_i, \quad (1)$$

where $F_{\text{resources}}$ is the total footprint for resources input, R_i is the consumed amount of resource i per year; NP_i is the natural productivity, expressed in t/ha/year, of each product/resource and, EF_i is the equivalence factor for the land use type producing products.

Equation (2) is used to estimate the energy category [14, 15].

$$F_{\text{energy}} (\text{gha}) = \sum (P_i / Y_i) * \text{EF}_i \quad (2)$$

where F_{energy} is the total footprint for energy input, P_i is the consumed amount of energy per year; Y_i is the average world



annual yield for the product i (or carbon dioxide absorbing capacity).

The waste footprint estimation was based on [9, 12]. It should be calculated in the same way as for resources, using the same energy intensity and/or natural productivity of the material that originated the waste. It is worth mentioning that, in the case of recycled waste (RW), the percentage of recovered energy by recycling should be subtracted from the total EF estimation. The waste footprint (urban and non-hazardous waste) can be estimated by Eq. (3):

$$F_{\text{waste}} \text{ (gha)} = \sum (W_i / NP_i) * EF_i, \quad (3)$$

where F_{waste} is the total footprint for waste output and, W_i is the produced amount of waste per year.

The emissions footprint ($F_{\text{emissions}}$) is calculated by Eq. (4), which represents CO₂ emissions related to fossil fuels consumed in the facility/organization.

$$F_{\text{emissions}} \text{ (gha)} = \sum (t\text{CO}_2e_i / Y_i) * EF_i \quad (4)$$

The total Ecological Footprint is evaluated based on Eq. (5).

$$\text{Ecological Footprint (gha)} = F_{\text{resources}} + F_{\text{energy}} + F_{\text{waste}} + F_{\text{emissions}} - \text{RW} \quad (5)$$

where $F_{\text{resources}}$ is the total resources footprint; F_{energy} is the total energy footprint; F_{waste} is the total waste footprint; $F_{\text{emissions}}$ is the total emissions footprint and RW is the total recycling waste footprint.

The next section presents the case study of a real textile facility in the North Region of Portugal and the proposed methodology applied to assess, mainly, its energy consumption.

Case study: textile industry in North of Portugal

The case study is focused on a textile facility unit with dyeing, printing and finishing processes. This unit uses as an input cotton fabric, which will receive treatment going through these processes. It is worth highlighting that this studied unit does not produce the fabric itself but treats it in order to obtain the desired final product ordered by its customers. It is worth to mention that the most required input by this facility was energy. In 2016 (year of available data), this Portuguese Textile Unit consumed about 2230 toe to produce near 3000 t of final product (colored, printed and finished fabrics) and its CO₂ emissions were around 7 ktCO₂e/year.

The facility's available data were collected and is presented in Table 1. Besides the inventory of the facility's

Table 1 Portuguese textile facility's collected data Source: prepared by the authors

| Input ^a | Values ^b | Units |
|------------------------------|---------------------|---------------------|
| Resources | | |
| Paper and labels | 7800 | kg |
| Water | 212,225 | m ³ |
| Energy | | |
| Natural gas (dry) | 1635 | toe |
| Diesel | 21.5 | toe |
| Propane | 0.8 | toe |
| Electricity | 566 | toe |
| Waste | | |
| Fabric (waste) | 430,000 | kg |
| CO ₂ e emissions | 7.0 | ktCO ₂ e |
| Output | | |
| Production (finished fabric) | 3 | kt |

^{a,b}All data were based on the facility's records for the year 2016

available data, conversions factors were used to estimate each category footprint. These factors are shown in the Table 2. Table 3 presents the equivalence factors used for each land category.

The total Ecological Footprint accounted, for the year 2016, summed up to 4890 gha. The calculations were supported in Eqs. (1)–(5) and data available on Tables 1, 2 and 3. The Resources Footprint estimation is 209 gha, representing less than 5% of the total Ecological Footprint, as the use of raw materials in the studied processes is limited. In the case of Energy Footprint estimation, the result is 2613 gha, which represents almost 50% of the total footprint and is mainly due to the use of high amounts of electricity and thermal energy. In the case of the Waste Category, the footprint reached about 90 gha, since there weren't a significant amount of disposable materials. Finally, for the CO₂e emissions footprint, the result is 1978 gha, also representing almost 50% of the total footprint, connected to the intensive use of energy in the analyzed processes.

It is worth mentioning that for this particular facility there is no waste recycling concerning these processes, so it was not considered in this study. The wastes considered in the analysis were pieces of fabric that either were not used or were cut-off. The liquid effluents were not accounted as well because they are usually disposed in the effluent treatment station, located next to the facility and run by the Portuguese

Table 2 Conversion factors
Source: prepared by authors

| Source | Embodied energy ^b (GJ/t) | Natural productivity ^c | Emission factor (tCO ₂ e/toe) | Land category ^d |
|---------------------|-------------------------------------|-----------------------------------|--|----------------------------|
| Cotton fabric | 10 | 1 (t/ha/year) | | Arable land |
| Paper and labels | 30 | 1 (t/ha/year) | | Forest land |
| Energy ^a | | | 3.078 | Fossil land |
| Water ^e | | 1500 (m ³ /ha/year) | | Forest land |

^aEnergy sources footprint and emissions footprint were estimated based on CO₂e emission factor and fossil land absorption rate (3.666 tCO₂e/toe) [9, 12, 35, 37]

^{b,c,d}Embodied energy, natural productivity and land category data were based on [9, 12, 35, 37]

^eTotal water consumption for these processes was due to steam generation and aqueous dyeing solutions. The company only kept record of the water used with chemicals. The water used for steam generation was estimated based on [24]

Table 3 Equivalence factors Source: prepared by authors based on [9, 12, 35, 37]

| Land category | Factor (gha/ha) |
|---------------|-----------------|
| Arable land | 2.1 |
| Forest land | 1.4 |
| Fossil land | 1.4 |
| Pasture land | 0.5 |

Government. This work considered the water used in the processes as a resource and avoided double counting by transferring the responsibility for the industrial effluents to the Treatment Station.

Furthermore, the built-up land related to the facility, occupied area and the existing machinery were not accounted as well. This paper assumed that its focus is the process of dyeing, printing and finishing fabrics and all resources (materials, energy and water) that should be acquired and disposed every month in order to deliver the final products. Also, the dyeing chemicals data were not available and it was not accounted in this study. However, according to the studied facility, the amount used for these components is not too significant, its impact being negligible in the global figures.

The energy category corresponds to more than 50% of the total EF estimation for the studied company and, natural gas was the most required fuel for the processes. It is important to highlight that the actual methodology for estimating EF does not include final products from studied processes in the analysis, i.e. finished fabrics. According to the actual methodology, final consumers should take full responsibility for the products [21]. However, the scientific literature indicates that the methodology should be updated and the responsibility for the final products should be divided amongst the producers and the consumers [26, 27]. If that was the case in the study, the total EF could reach up to 8000 gha and the energy category would correspond to about 30% of the total result. In addition, if the producer alone took responsibility for the products and included it in the analysis, the total EF

would be up to 10,000 gha and energy would be about 25% of the total.

The analysis showed that energy consumption is a significant portion of the total EF of the textile facility. Energy, specially thermal energy, is one the most required resource by processes such as printing, dyeing and finishing, that leads to the need to study mitigation measures in order to promote increased efficiency and consumption reduction [17, 19, 28, 29].

Energy consumption mitigation measures

Some mitigation measures were identified and could be implemented in the facility to reduce energy consumption, CO₂e emissions and, consequently, the EF.

One energy consumption mitigation measure that could be implemented is the reduction and control of compressed air leaks. In 2016, it was verified, in the textile installation, an average leakage of about 40% of the produced compressed air. According to [24, 30–33], considering a frequent maintenance of the compressors, it could reduce its leakage to about 10% and consequently reduce electricity consumption and save up to 10 toe/year.

Other example of mitigation option is to install equipment to control gas combustion and avoid unnecessary steam generation in boilers, which can reduce natural gas consumption by 6% [24, 30, 33]. In the case of the facility, it can save up to 48.7 toe/year in each boiler. Considering that the facility has 2 boilers, the total reduction can reach up to 97.4 toe/year.

Also, installation of an air/water heat exchanger in the finishing machinery could save about 5% of total energy [31–33]. In the case of the studied facility, there are two machines that, together, can save up to 93.4 toe/year, by installing the referred equipment.

Moreover, an additional measure is the installation of photovoltaic panels to produce electricity in loco [24, 32, 33]. According to the company, there is an available area of

about 520 m², in which 300 panels could be installed. It was estimated that it would generate 112 MWh per year, considering a capacity factor of 15% [32–34]. This alternative could reduce the consumption of electricity from the grid in about 10 toe/year. Considering that this is a renewable energy source it would reduce CO₂e emissions in about 30 tCO₂e/year. Furthermore, the replacement of existing lighting for LED devices could save up to 9.5 toe/year in electricity consumption [30, 33, 35].

All the options can be implemented at the same time, so the total energy reduction is a sum of all energy reductions presented in this study. The total energy reduction potential for the studied facility is up to 220.5 toe/year. It consequently would reduce the EF of this facility by approximately 260 gha, which corresponds to a 5.3% of the company's EF.

Final remarks

According to National Laws, Portuguese facilities consuming more than 500 toe/year are framed as energy-intensive facilities [36]. In the case of the textile facility analyzed in this study, the energy consumption is about 2300 toe/year which is higher than the limit presented. Thus it should be analyzed in order to implement an Energy Consumption Rationalization Plan.

The energy consumption mitigation proposals presented in this paper are considered as a first step towards implementing the referred plan. According to the results, it could reduce about 10% of the total energy consumption for the textile facility studied.

Furthermore, the bottom-up approach required by the EF methodology allows identifying the consumption by type of energy and resources. Consequently, it was possible to determine the processes' segments that are most energy-intensive. In the case analyzed in this paper, the processes of dyeing and finishing were the largest energy consumers, and the most consumed type of energy was thermal energy. This methodology allowed to investigate each part of the studied processes including energy efficiency and, at the same time, it enabled a global efficiency analysis to be done, that includes not just energy, but all the resources.

It is worth mentioning that this is an important analysis, especially for Portugal, that is part of an European Union group of countries that are engaged on the task force to reduce energy consumption in Textile Sector [33]. Countries like Germany, Spain, Italy, France and United Kingdom, together, account for about three quarters of European Union textile production and have reported projects concerning energy efficiency in the sector [33]. However, unlike these members of the task force, Portugal have showed less improvements over the years, because in the Portuguese textile sector, there are still many small facilities that

function with equipment with very low efficiency and do not keep record of their consumption [23, 33]. This study can encourage these facilities to start reporting their data and be engaged on programs to reduce its energy consumption through increased investments in the latest best available industry practices, even though the National Government does not require it yet. Besides it, Portugal is strongly dependent on resources import, such as energy and materials, as mentioned before. The Global Ecological Footprint for Portugal, in 2016, was 3.88 gha/person [7]. The Portuguese biocapacity, in 2016, was 1.51 gha/person, so it has a deficit of 2.37 gha/person, which explains the Portuguese high dependency on international resources [7] and by increasing energy efficiency in industrial sectors, it could reduce its Ecological Footprint deficit.

Overall, the calculation of the EF in the textile facilities can be used as a tool to analyze the processes' energy efficiency and to quantify the global impact of the implementation of mitigation measures in the energy field. The result is an indicator shown in a common unit, gha (global hectare) and it can be easily used to compare energy-intensive processes and industrial sectors. In addition, it can be used to analyze how each sector can impact the country's total demand for resources.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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