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# Ecological footprint analysis based awareness creation for energy efficiency and climate change mitigation measures enhancing the environmental management system of Limassol port

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ABSTRACT

Sea ports are very complex systems related to a wide variety of issues, the most important being waste production as well as water, air and soil releases. Furthermore, in port areas, several activities are carried out that may cause significant environmental impacts such as fisheries, industrial activities and storage of hazardous materials. Setting objectives and goals in terms of a comprehensive environmental management plan is of a great importance for sea ports. The main scope of this study is to introduce a novel approach to rationalize the environmental management strategies of sea ports based on the reduction of their ecological footprint. The object of the study is the Limassol sea port, a main cargo and cruise home port of the Mediterranean that serves one of the largest shipping fleets worldwide. In terms of this study, the most significant environmental aspects of the Limassol sea port are identified. An analysis of the main results of the calculation of the ecological footprint and carbon footprint is presented, by applying the Ecological Footprint analysis methodology. This study aims to deliver a comprehensive methodology that links the results of ecological footprint analysis with the environmental objectives of an ISO 14000 environmental management system.



## 1. Introduction

Sea ports are organizations that provide multiple activities including ship-related activities such as vessel traffic, cargo-related activities like cargo handling and storage and land transport to and from the port. Sea ports are considered as bodies of wealth production but also as sources of waste absorption, land and sea users and as a result environmental polluters. Sea ports requirements for resources and space have increased drastically their environmental impact. Environmental hazards resulting from sea ports activities include ship discharges and emissions, spills and leakage from ships, handling, hazardous materials and waterfront industry discharges. Sea ports depend on ecosystem for resources as well as spaces to host the required infrastructures and to absorb the produced wastes.

Cyprus ports authority is increasingly concerned with achieving and demonstrating sound environmental performance by controlling the impacts of Limassol sea port activities on the environment, consistent with its environmental policy and objectives. To this end, the authority is committed to adopt innovative solutions towards a sustainable management of Limassol port environmental performance. A well-established methodology employed to quantify the credits of ecosystem products and services in terms of the required bioproductive land and sea to supply the human activities is the ecological footprint (EF). The area of land or sea that is available to support a specific use is termed biological capacity (biocapacity) and is equal to the biosphere's ability to satisfy human demand for material consumption and waste disposal. EF and biocapacity calculation includes six forms of land use: cropland, grazing land, fishing ground, forest land, built-up land and also the uptake land to accept the carbon footprint.

The main scope of studies conducted in the past concerning the environmental performance of sea ports was the development of indicators to characterize the environmental impact of the usual activities in ports. Such rating systems include the Self Diagnosis Method (Darbra et al., 2004), the Strategic Overview of Significant Environmental Aspects (Darbra et al., 2005), the sustainable environmental management indicators for port authorities (Peris-Mora

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**Nomenclature**

*Symbols*

| | |
|---|---|
| $A_{CS}$ | global total continental shelf area (fishing grounds) [ha] |
| CC | carbon content of wet weight fish biomass (fishing grounds) [t C] |
| DR | discard rate for bycatch (fishing grounds) [−] |
| $EF_C$ | carbon ecological footprint [global ha] |
| EQF | equivalence factor [global ha/ha] |
| $F_{Crop}$ | amount of feed available from crop grown specifically for fodder (grazing land) [ha] |
| $F_{Mkt}$ | amount of feed available from general marketed crops (grazing land) [ha] |
| $F_{Res}$ | amount of feed available from crop residues (grazing land) [ha] |
| $P_{Gr}$ | grazing land ecological footprint [global ha] |
| $Q_{S,i}$ | estimated sustainable catch for species group i (fishing grounds) [fishing yield] |
| $P_C$ | annual emissions of carbon dioxide (carbon footprint) [t $CO_2$] |
| PPR | primary production requirement (fishing grounds) [−] |
| $PP_S$ | global sustainable harvest (fishing grounds) [−] |
| $S_{Ocean}$ | fraction of anthropogenic emissions sequestered by oceans (carbon footprint) [%] |
| TE | transfer efficiency of biomass between trophic levels (fishing grounds) [%] |
| TL | trophic level of the fish species in question (fishing grounds) [−] |
| TFR | calculated total feed requirement (grazing land) [ha] |
| $Y_C$ | annual rate of carbon uptake per hectare of forest land (carbon footprint) [t $CO_2$/ha] |
| $Y_M$ | average marine yield (fishing grounds) [fishing yield/ha] |

*Abbreviations*

| | |
|---|---|
| EF | ecological footprint |
| EMS | environmental management system |
| ESPO | European Sea Ports Organization |

et al., 2005). Issues regarding the application of environmental management systems and policy procedures in sea ports were also addressed in previous studies (Saengsupavanich et al., 2009; Marazza et al., 2010; Machado et al., 2013). On the other hand, EF research studies include attempts to further development of the methodology per se (Kitzes et al., 2007; Ewing et al., 2010) as well as to link EF and sustainability schemes (Cucek et al., 2012; Valada, 2010). Some studies also concerned the EF of particular systems, such as waste streams (Herva et al., 2010), nectarine production (Cerutti et al., 2010), swine manure fertilization in orchard (Cerutti et al., 2011) fruit production systems (Cerutti et al., 2013), and even municipalities (Buratti and Da Vinci, 2009). To the knowledge of the authors only Millan et al. (2010) conducted a study regarding the EF of a sea port, whereas no previous study is found in the literature with the aim to link the environmental performance of a port in terms of its EMS with its EF. To this end the research question which arises is to which extend the ecological footprint analysis could be incorporated into the environmental targets and objectives of an organization, with the subject of this study being a sea port.

The scope of this study is to quantify the EF of the Limassol port and to provide useful guidelines for the sustainable environmental management of sea ports in general. Following a brief section, in which the theoretical background and the methodology of this study is presented, a comprehensive literature review regarding previous studies concerning the environmental impact of sea ports and the EF is provided. In Section 4 the EF of Limassol sea port is quantified in Section 4.1 and in Section 4.2 the footprint analysis is used to prioritize the environmental management objectives of the sea port EMS.

## 2. Theoretical background and methodology

In this section, the theoretical background based on which this study was developed is presented. Useful information with regard to the subject of this study, the Limassol port, is given, in an effort to advise the readership for the environment and the conditions under which the study's principles are implemented. The main aspects of the ecological footprint calculation processes as well as of the environmental management systems according to the ISO 14000 are presented in Sections 2.2 and 2.3 respectively. Finally in Section 2.4 the employed methodology is introduced and explained.

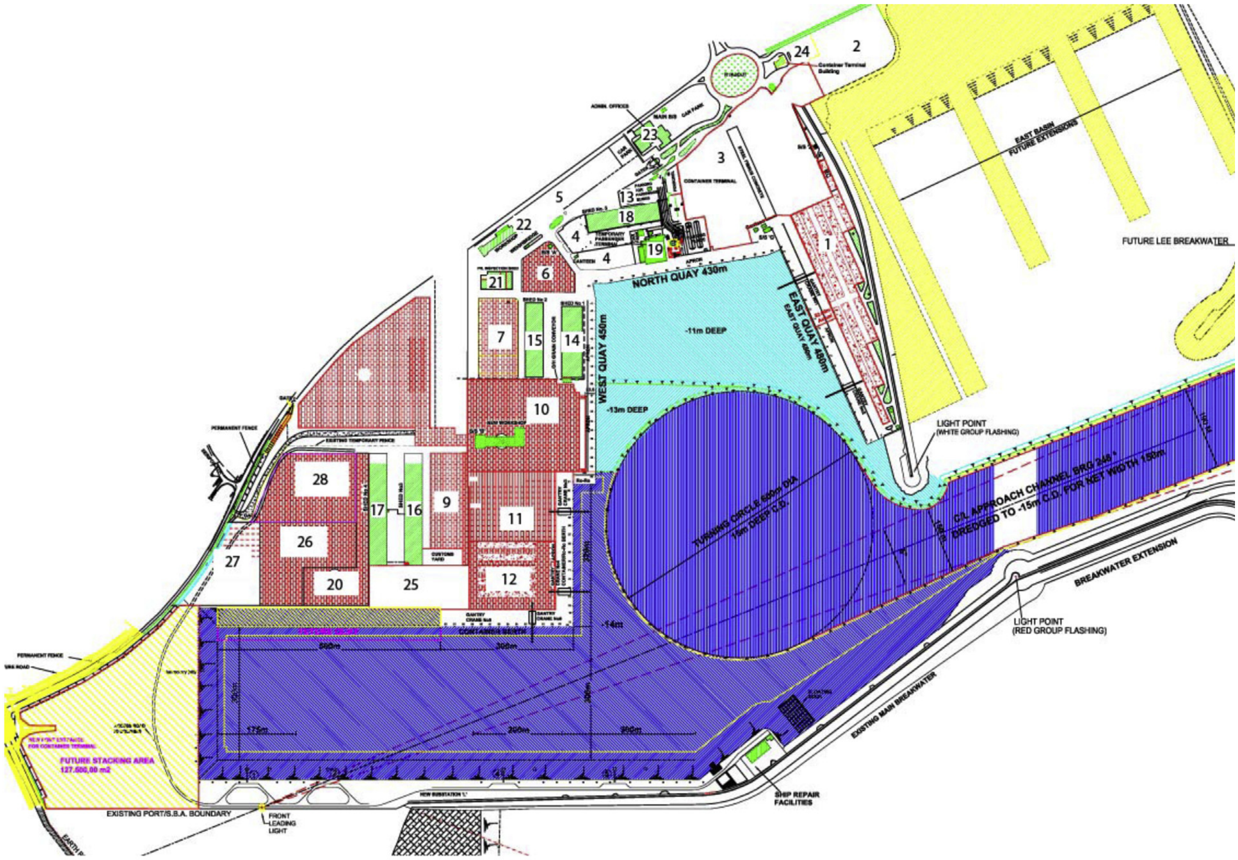
### 2.1. Cyprus shipping fleet and the Limassol Port

Cyprus is a major ship management center worldwide with a total of around 60 ship management companies operating in its territory. As of 2014, the Cyprus ship registry ranks tenth among international fleets – with 1857 ocean going vessels of a gross tonnage exceeding 21 million tonnes (Cyprus Department of Merchant Shipping, 2014). With Cyprus an established player in the shipping industry, Limassol port (geographical location 34°39′00″N 33°01′00″E), has accumulated importance over time and is a center for numerous shipping companies. Considered as the main port of Cyprus, it commenced operations in 1974. It provides services to ships, loading/unloading of cargo and passenger traffic. The marine area of the port is 1 km$^2$ and its land area is 1.3 km$^2$. The quays at Limassol port have a total length of 1980 m and the covered spaces comprise 5 warehouses of total area 39,760 m$^2$. The annual amount of cargo handled in Limassol port exceeds 3.5 M tonnes whilst there are roughly 1 million passenger arrival and departures every year (Cyprus Ports Authority, 2014). The Cyprus Ports Authority currently employs at Limassol Port 242 people. The significance of the Cypriot shipping fleet as well as the size of Limassol sea port, indicate the importance of the investigated case study.

The layout of the existing infrastructure at the Limassol Port is depicted in Fig. 1.

### 2.2. Ecological footprint (EF)

The EF is a resource accounting tool that measures how much bioproductive land and sea is available on earth, and how much of this area is required for human use (Kitzes et al., 2007). The area of land or sea available to serve a particular use is called biological capacity (biocapacity), and represents the biosphere's ability to meet human demand for material consumption and waste disposal. The first academic publication about the EF was by William Rees in




| | | |
|---|---|---|
| 1. New Passenger Terminal | 2 Container Terminal | 3. Container Terminal |
| 4. Empty Space | 5. Stocking Area for Imported Cars | 6. Empty Space |
| 7. Stocking Area for Imported Cars | 8. Container Section | 9. Container Section |
| 10. container section | 11. Container Section | 12. Container Section |
| 13 Parking Area for Buses (4400 m²) | 14 Shed No 1 (7200 m²) | 15 Shed No 2 (6080 m²) |
| 16 Shed No 3 (10000 m²) | 17 Shed No 4 (10000 m²) | 18 Shed No 5 (6400 m²) |
| 19 Passengers Terminal (2550 m²) | 20 New Workshop (2650 m²) | 21 Produce Inspection Shed (3190 m²) |
| 22 Old Workshop (1800 m²) | 23 Administration offices (3300 m²) | 24 Container Terminal Offices (325 m²) |
| 25 Paved area for containers (20000 m²) | 26 Paved area for containers (50000 m²) | 27 Paved area for containers (24000 m²) |
| 28 Paved area for containers (31000 m²) | | |

**Fig. 1.** Layout of Limassol port infrastructure.

1992 (Rees, 1992). It was though not before 2006 when EF calculation methods converged to a single standards (Global Footprint Network, 2014). EF and biocapacity calculations cover six land use types: cropland, grazing land, fishing ground, forest land, built-up land, and the uptake land to accommodate the carbon footprint (Ewing et al., 2010).

- Cropland consists of the area required to grow all crop products, including livestock feeds, fish meals, oil crops and rubber.
- The grazing land footprint measures the area of grassland used in addition to crop feeds to support livestock. Grazing land is calculated as follows:

$$P_{GR} = TFR - F_{Mkt} - F_{Crop} - F_{Res} \quad (1)$$

- The fishing grounds footprint is calculated based on the annual primary production required to sustain a harvested aquatic species (PPR). PPR is calculated as follows:

$$PPR = CC*DR*\left(\frac{1}{TE}\right)^{(TL-1)} \quad (2)$$

DR is assigned the global average value of 1.27 and TE is assumed to be 0.1 for all fish. The sustainable annual harvests of 19 different aquatic species groups are used to estimate the annually available primary production used to calculate marine yields. The world average marine yield YM, in terms of PPR, is given by

$$Y_M = \frac{PP_S}{A_{CS}} \quad (3)$$

whereas PP is given by

$$PP_S = \sum (Q_{S,i}*PPR_i) \quad (4)$$

- The forest land footprint measures the annual harvests of fuelwood and timber to supply forest products.
- The built-up land footprint is calculated based on the area of land covered by human infrastructure
- The uptake land to accommodate the carbon footprint is the only land use type included in the EF which is exclusively dedicated to tracking a waste product: carbon dioxide.

$$EF_C = \frac{P_C(1 - S_{Ocean})}{Y_C}*EQF \quad (5)$$

$S_{Ocean}$ is assigned the global average value of 0.35.

For each land use type, the demand for ecological products and services is divided by the respective yield to arrive at the footprint of each land use type. EF and biocapacity are also scaled with equivalence factors to convert this physical land demanded to world average biologically productive land, usually expressed in global hectares. Both the equivalence factors and the yield factors are given in Table 1. This table aims to provide the significance of the built-up Land among the total of the area types that are covered by the selected biocapacity calculation. The calculation of the EF, the evaluation of the current ecological supply and demand and also the historical trends provide a base for setting goals, identifying options for action and observing progress of the determined goals.

**Table 1**
Equivalence and yield factors, 2007 (Global Footprint Network, 2014).

| Area type | Equivalence factors [gha/ha] | World average yield factors [−] |
|---|---|---|
| Cropland | 2.51 | 1.0 |
| Forest | 1.26 | 1.0 |
| Grazing land | 0.46 | 1.0 |
| Marine and inland water | 0.37 | 1.0 |
| Built-up land | 2.51 | 1.0 |

### 2.3. Environmental management systems (EMS)

Environmental management system (EMS) refers to the management of an organization's environmental programs in a comprehensive, systematic, planned and documented manner. EMS includes the planning and resources, as well as the organizational structure required for the development, implementation and maintenance policy for environmental protection (Sroufe, 2003). EMS is typically reported based on the International Organization for Standardization (ISO) 14001 to help understand the EMS process.

ISO 14001 standard specifies requirements for an environmental management system to enable an organization to develop and implement a policy and objectives which take into account legal prerequisites as well as information about significant environmental aspects. The standard is intended to apply to all types of organization and to accommodate diverse geographical, cultural and social conditions. ISO 14001 enables sea ports to develop an environmental policy, establish objectives and processes to achieve the policy commitments, take action as needed to improve its performance and demonstrate the conformity of the system to the requirements of the standard. The overall aim of ISO 14001 is to support environmental protection and prevention of pollution in balance with socio-economic needs (EN ISO 14001:2004).

Of crucial importance for the successful implementation of an ISO 14001 system are the environmental objectives and targets of the EMS. The environmental objectives are defined as the overall environmental goals, consistent with the environmental policy set by the organization itself to achieve. The environmental targets are the detailed quantified performance requirements, applicable to the organization, that arise from its environmental objectives and that need to be set and met in order to achieve those objectives. The appropriate assignment of realistic objectives and achievable targets requires a viable prioritization strategy.

### 2.4. Methodology

The methodology applied in this study is summarized in Fig. 2. In Section 4, the available feedback from Cyprus Ports Authority regarding Limassol sea port activities for the year 2012 was employed to calculate the EF of the organization. Particularly:

- The area of land covered by the port infrastructures was used to quantify the built up land.
- The available data on energy, fuel and water consumption as well as the information regarding the waste disposal were employed for the definition of the carbon footprint.
- The rest land use types were deduced from the average national EF (Global Footprint Network, 2013), based on the assumption that the port does not present any particular activities related either to grazing and forest land or cropland. Also, although being a sea port, Limassol port is a cargo and cruise home port and not a fishing port, therefore fishing grounds were deduced from the average national EF.

All land use types were quantified based on the Ecological Footprint Analysis as derived by the Global Footprint Network Methodology (2014).

In Section 4.2 the environmental objectives of Limassol sea port EMS were allocated, based on specific criteria to the EF land use types. Based on the biocapacity of Limassol port the EMS objectives were prioritize, rationalizing in this way the environmental planning of the port. The environmental objectives were retrieved from the under development ISO 14001 EMS of the Limassol sea port. The result of this analysis provides a clear view with regard to the

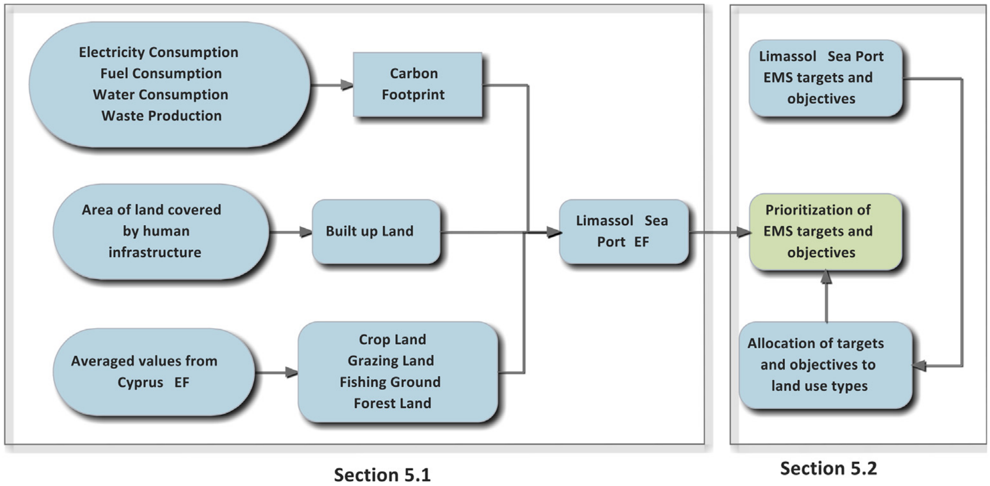



**Fig. 2.** Study methodology flow chart.

environmental strategies that need to be adopted towards improving the environmental performance of Limassol sea port.

## 3. Literature review

In this chapter, a brief literature review regarding previous studies conducted for the environmental impact of the operation of sea ports, as well as for the penetration of the ecological footprint in research studies is conducted. The initiatives implemented in the European Region by port authorities towards mitigating the negative impact of their operation on the environment is also presented in this chapter.

### *3.1. Previous studies on the environmental impacts of sea ports*

Several studies were conducted in the recent past regarding the environmental impact of sea ports and appropriate methodologies were developed aiming to their mitigation. Some studies were also involved with the development of indicators to characterize the environmental impact of usual activities in ports. Darbra et al. (2004) developed a methodology in order to evaluate the performance of the environmental management of sea ports. The methodology called Self Diagnosis Method was applied in sixty sea ports. It focused on reviewing the management activities and procedures that have environmental impacts and the way port authorities dealt with the significant environmental aspects. In a further study of Darbra et al. (2005) a new methodology, called Strategic Overview of Significant Environmental Aspects (SOSEA), was introduced. This methodology aimed to help port managers to identify significant environmental aspects and to strengthen the awareness about them in order to prioritize work in environmental management. Peris-Mora et al. (2005) proposed a system of sustainable environmental management indicators to be used by any port authorities, named INDAPORT. The purpose of their study was to identify all the activities that are usually performed in a port area and analyze them for any potential environmental impacts and risks. For this purpose, they performed an environmental analysis of port activities with the scope of designing an indicators system. Darbra et al. (2009) examined twenty six European ports to define their requirements for environmental information. Aspects that were covered by the research included port profile description, environmental management activities, environmental needs and existing monitoring practices. The study reflected the variety amongst European ports and their environmental performances. Saengsupavanich et al. (2009) integrated the procedures of ISO 14001 and port state control to establish environmental performance indicators, specific to industrial ports and estates. Marazza et al. (2010) developed a method, with the objective to rank the environmental aspects in environmental management systems. This particular method was used to define and classify the importance of the environmental aspects of a local authority, as a base for the implementation of an environmental management system (EMS). Machado et al. (2013) investigated a case study in Brazil regarding the environmental policies procedures of inland navigation and port management. The main objective of this study was to demonstrate the Brazilian environmental legislation and policies towards the development of navigation and port management. Millan et al. (2010) evaluated the externalities of ports in northern Spain by calculating the EF of a port in northern Spain. They presented an analysis of the main results of the calculation of the EF and carbon footprint produced by the activity of a northern port in Spain, using a compound financial accounts method. The results were compared with those derived for Gijon Port Authority in 2006. In this study eco-efficiency indicators were also calculated and compared. Anastasopoulos et al. (2011) developed a study about the conversion of Greek ports to green ports. In this study, modern, eco-friendly and cost-efficient ideas to enhance the competitiveness and to promote Green Ports were presented by taking into account the current situation of the ports, as well as the current legislation regarding the protection of the environment.

From the above analysis it is obvious that studies conducted in the past regarding the environmental performance of sea ports aim to the development of indicators to characterize the environmental impact of ports activities, as well as the application of environmental management systems and policy procedures in sea ports.

### *3.2. Previous studies on the ecological footprint (EF)*

Although EF calculation methods have converged thanks to standards released in 2006 (Global Footprint Network, 2014), there are already some few studies found in literature regarding the implementation of EF principles to several systems and boundaries. Kitzes et al. (2007) investigated the current methodologies to calculate national EF accounts. In this study, a method for calculating the EF as well as the units that are used to measure it was presented. Using data and calculations from multiple sources, they indicated that in 2003 there were about 11.2 billion global hectares of area available. In that same year, humanity demanded products and services of 14.1 billion global hectares. In this study, it was stated that if this procedure continues, global ecosystems will be put at serious risk of degradation or collapse. They indicated the need for reducing humanity's EF and they proposed an approach to meet these goals called “Shrink and Share”. Cucek et al. (2012) also presented an overview of footprints as defined indicators that can be used to measure sustainability. This study also focused on composite footprints, combining two or more individual footprints. The authors performed a comprehensive overview of the several tools for footprints' evaluation, including some of the numerous carbon footprint calculators, available calculators for other footprints, graph-based tools as well as mathematical programming tools. Valada (2010) also delivered a review and further analysis regarding the implementation of the EF as an indicator of environmental sustainability. The overall goal of this report was to understand the utility and applicability of the concepts and application, done by the Global Footprint Network, of the EF and biocapacity, in the context of environmental sustainability. Ewing et al. (2010) developed a calculation methodology for the national footprint accounts in support of the Global Footprint Network. In this report the methodology for calculating the EF and biocapacity utilized in the 2010 Edition of the National Footprint Accounts is described and researchers and practitioners are provided with information to better understand the calculation methodology of national footprint accounts.

Herva et al. (2010) developed a comprehensive methodology to estimate the EF of wastes treatment considering a closed cycle modeled through a plasma process. Wastes from industry can be treated in a thermal plasma gasification process, and, by developing a methodology to describe this process, the EF of hazardous wastes was calculated. Cerutti et al. (2010, 2011, 2013) applied the EF methodology in different cases for the calculation of the sustainability assessment of nectarine production (2010), swine manure fertilization in orchard (2011) and for fruit production systems in Northern Italy (2013). In all three cases Cerutti et al. employed the Ecological Footprint Analysis as derived by the Global Footprint Network. Buratti and Da Vinci (2009) developed the application of the EF method in Jokkmokk municipality (Sweden). The calculation was preceded by the data collection, after that the data had been converted in the correspondent territory area, obtaining a final value reflecting as best as possible the local situation. In the end there had been a comparison of the results with the ones for Montechiarugolo (Italy). Gondran (2010) estimated the EF as a follow-up tool for an administration. The consequences of methodological liberties within the EF estimation identified and its use as a decision aid tool on the scale of a public organization. The method was developed and validated for the Vanoise National Park which undertook to reduce its EF by 10% between 2009 and 2007. The methodological liberties inherent to EF analysis on an organization scale generate methodological choices that may influence the results in terms of environmental impact hierarchy and priority of actions.

The conducted EF studies reveal that currently the main research concern in this field is the further development of the EF methodology per se, as well as its validation through its application on particular boundaries and systems.

### *3.3. Initiatives in the European Region towards mitigating climate change impacts at sea ports*

Currently in the European Region, some important initiatives are being carried out aiming to mitigate the negative environmental impacts of sea ports operation. More than half of the European ports have a program to increase energy efficiency and 1 out of 3 EU ports measures or estimates its carbon footprint. Half of the EU ports take measures to reduce their carbon footprint (European Sea Ports Organization (ESPO), 2014). Most EU Port Authorities at least those that aiming to manage their ports as green ports, are implementing a certified EMS based on well-established standards (ISO14001, EMAS).

The European Sea Ports Organization (ESPO), representing the port authorities, port associations and port administrations of the sea ports of the Member States of the European Union and Norway, issued in 2012 its green guide entitled “Towards excellence in port environmental management and sustainability” (European Sea Ports Organization (ESPO), 2012). In this guide, the vision of European port authorities towards sustainability in port areas is defined. The European port authorities re-establish their environmental policy code and commit themselves to continuously work towards improving their environmental performance through focused action. This report also provides guidance to the members of ESPO on how to work towards fulfilling their environmental objectives and commitments.

With the “Port Performance Indicators Selection and Measurement” (PPRISM) project, ESPO took a first step to establish a culture of performance measurement in European ports (European Sea Ports Organizations (ESPO), 2012b). This project delivered a shortlist of indicators that form the basis of a future European Port Observatory which would take the form of a Port Sector Performance Dashboard. The Dashboard contained well defined indicators that were accepted by stakeholders and measured the performance trends in the European port sector. Following PPRISM, the “Mediterranean's Port's Contribution to Climate Change Mitigation” (Climeport) project proposed the assessment of different methodologies in order to combat the global climate change arising from sea ports activities (Mediterranean's Port's Contribution to Climate Change Mitigation – Climeport, 2014). The project took place in several countries of the Mediterranean area involving a group of the largest ports committed to tackling climate change. The project aimed to develop and implement solutions in order to improve the general climate conditions by means of actions in maritime and inland transport, energy saving and efficiency, implementing the world port climate declarations as well as designing an environmental indicators system as footprint according to $CO_2$ levels.

## 4. Results and discussion

### *4.1. Limassol sea port ecological footprint (EF)*

#### *4.1.1. Build up land footprint*

The built-up land footprint was calculated based on the area of land covered by human infrastructure, including transportation, housing and industrial structures (Ewing et al., 2010). For Limassol port the calculation was based on the area of land covered by human infrastructure (warehouses, offices, workshops, passenger terminals, roads). The total built up land was determined from the data given in Table 2. Particularly following spaces were included: passenger terminals, container terminals, stocking areas, sheds, workshops, paved areas, roads and parking areas, administration offices, berths, gardens and pasture areas. The area occupied by buildings corresponds to 233.6 ha and the built-up land EF was calculated to be 586.3 gha.

#### *4.1.2. Carbon footprint*

Carbon dioxide is released to the atmosphere due to the activities in Limassol port in numerous ways. Carbon EF of fossil fuel consumption is calculated by estimating the biologically productive

**Table 2**
Built up land EF, Limassol sea port, 2012.

| | |
|---|---|
| Total port area | 128 [ha] |
| Pasture or garden areas | 0.3 [ha] |
| Sea area (between the breakwaters) | 90 [ha] |
| Filled land for construction, tracks | 11.25 [ha] |
| Construction materials (building area) | 0.54 [ha] |
| Berths | 3.48 [ha] |
| Total | 233.6 [ha] |
| Built up land EF | 586.3 [gha] |

area needed to assimilate this waste product of the human activity. $CO_2$ releases in the atmosphere resulting from the following activities in Limassol sea port were considered:

i. electricity consumption,
ii fuel consumption,
iii water consumption.
iv waste decomposition

The latter source was analyzed in different manners, depending on the type of waste and its treatment methodology.

- Regarding the electricity consumption, Cyprus power generation system consists of three thermal power stations at Moni, Dhekelia, and Vasilikos, with a total installed capacity of 1438 MWe (Fokaides and Kylili, 2014). All stations use HFO for the steam turbine units and gasoil for the gas turbine units, resulting to an emission factor of 0.8 kg $CO_2/kWh_E$ (Fokaides et al., 2014). Limassol sea port electricity consumption for the year 2012 reached 3,073,610 kWh of electricity (Table 3). Electricity was consumed for the loading and uploading of ships, as well as to satisfy the energy demands of sea ports buildings. The carbon EF of the electricity consumption was estimated to be 457 ha.
- As for the transport and heating fuels, diesel and gasoline are used. Cyprus Port Authority consumed for the activities of Limassol sea port 560 tonnes of fuel were consumed in 2012. The carbon footprint of fuel consumption is estimated to be 320 ha.
- The energy required to carry the 142,500 tonnes of consumed water in 2012 to Limassol sea port from Kouris dam, located in a distance of 15 km, is 5800 MWh. Part of this energy is satisfied from gravitational forces, whereas 870 $MWh_E$ are consumed for pumping purposes. The carbon footprint for water consumption amounts 129 ha.
- For the waste decomposition, the methodology described in Herva et al. (2010) was applied. Following waste categories were taken into consideration: garbage (8.1 kt), asbestos-containing materials (15 t), waste recovered oil pollution (0.3 t), sludge (2.1 kt), batteries (0.5 tn) and motor oil (2.1 tn). The total $CO_2$ emitted for the decomposition of this waste is estimated to be 1292 ha.

The total breakdown of the carbon footprint of Limassol sea port for year 2012 is depicted in Fig. 3.

**Table 3**
Carbon EF, Limassol sea port 2012.

| Source | Value | t $CO_2$ | Area [ha] |
|---|---|---|---|
| Electricity [kWh] | 3,073,610 [kWh] | 2459 | 457 |
| Fuel [toe] | 560 [toe] | 1725 | 320 |
| Water consumption [$m^3$] | 142,392 [$m^3$] | 696 | 129 |
| Waste | – | 1292 | 239 |
| Total | – | 6172 | 1145 |
| Carbon EF | – | – | 1442.7 [gha] |

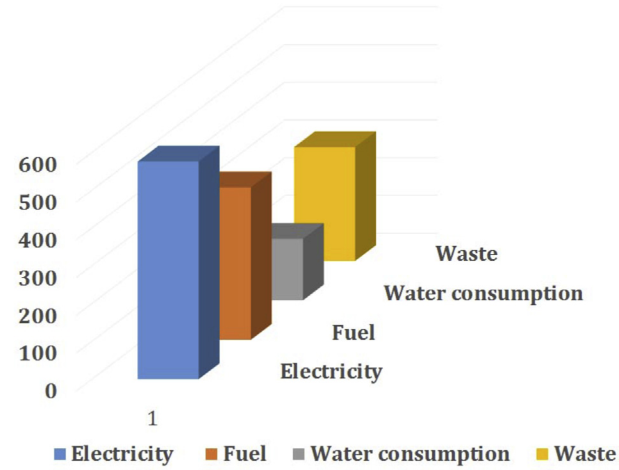



**Fig. 3.** Limassol sea port carbon footprint breakdown.

*4.1.3. Other land use types*

The rest land use types were deduced from the average national EF (Global Footprint Network, 2013). The EF of the rest land use types is summarized in Table 4 whereas the EF of Cyprus is provided in Table 5. The deduction was based on the number of employees at Limassol sea port, as well as the average time spent at port's facilities.

*4.1.4. Total EF*

In Fig. 4 the total EF of Limassol sea port is presented. According to the summarized results, the EF of Limassol sea port equals to 2182.1 gha. As an order of magnitude, the calculated EF is in good agreement with the findings of previous studies regarding sea ports. Millan et al. (2010) for example defined the EF of Gijon port in northern Spain to be equal to 5125.8 ha. It should be stated though that in this study the materials embodied energy was also considered, accounting for more than half of the entire EF (58%). Also Gijon sea port handles 6 Mt of cargo annually, which is around 70% more than the cargo of Limassol sea port. Therefore the deviation in the EF of the two sea ports is well justified.

Another important finding is related to the per capita EF in gha in Cyprus. According to the data provided in Table 4 the average EF per capita in Cyprus reaches 4.44 gha. Taking into consideration the number of the sea port employees (242) (see Section 2.1), the average time spent annually in the port (8 h shift, 225 days annually), as well as an average residence time of 2 h per passenger, the per capita EF of the Limassol sea port reaches 7.9 gha. This number indicates that the EF of the activities in the Limassol sea port is almost 2 times higher, compared to the per capita demand in bioproductive land for the rest of the activities in Cyprus.

With regard to the allocation of the EF to different land use types, it is obvious that the carbon EF causes the biggest footprint. Particularly activities related to $CO_2$ disposal account for the 66% of the total EF of Limassol port. Built-up area contribute to a high

**Table 4**
Cropland, grazing land, forest land and fishing grounds footprint Limassol sea port 2012.

| | | |
|---|---|---|
| Cropland EF | [gha] | 96 |
| Grazing land EF | [gha] | 18.5 |
| Forest land EF | [gha] | 33 |
| Fishing grounds EF | [gha] | 5.6 |
| Total | [gha] | 153.1 |

**Table 5**
Cyprus EF (Global Footprint Network, 2013).

| | | |
|---|---|---|
| Population | [–] | 1,077,000 |
| Total ecological footprint | [million gha] | 4.78 |
| Cropland footprint | [gha per capita] | 1.19 |
| Grazing land footprint | [gha per capita] | 0.23 |
| Forest land footprint | [gha per capita] | 0.41 |
| Fishing grounds footprint | [gha per capita] | 0.07 |
| Carbon footprint | [gha per capita] | 2.54 |
| Built up land footprint | [gha per capita] | 0.00 |
| Per capita ecological footprint | [gha per capita] | 4.44 |

percentage of footprint with 27% of the total EF. The rest of the land use types require only a small portion of the EF.

### 4.2. Limassol sea port environmental management system (EMS)

Cyprus ports authority developed an EMS in accordance with the requirements of the ISO 14001 standard to continuously improve the environmental performance of Limassol sea port. Within its EMS, Limassol sea port authorities developed specific procedures to identify the environmental aspects of its activities, and to determine those aspects that could have significant impact on the environment. The Limassol port authorities will maintain a program for achieving its EMS objectives and targets that includes the designation of responsibility for achieving objectives and targets, as well as the means and time-frame by which they are to be achieved.

Limassol sea port authorities will ensure that the significant environmental aspects of the port should be taken into consideration in implementing its EMS. To this end, the findings of the EF analysis are expected to serve as a useful feedback to define the environmental aspects of greater significance. The environmental objectives and targets within the Limassol sea port, are measurable, where practicable, including the commitments to prevention of pollution, to compliance with applicable legal requirements and with other requirements.

As concluded by the calculation of the EF of the Limassol sea port, the footprints that need to be considered are the carbon footprint, as well as the footprint resulting from the built up land. With regard to the carbon EF, following activities are considered as related to its magnitude:

- Passenger terminal operation
- Workshop operation
- Office operation
- Building maintenance
- Mobility of passengers in and traffic of vehicles in port

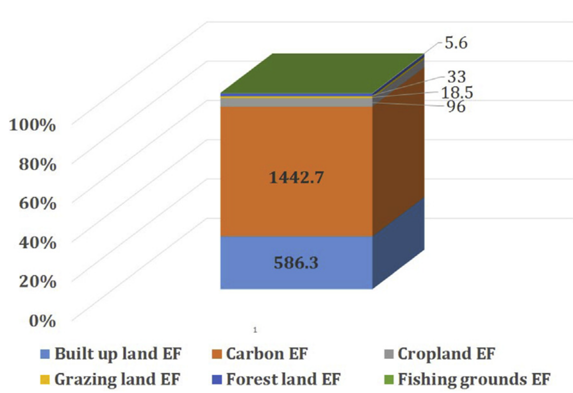



**Fig. 4.** Limassol sea port ecological footprint.

- Temporary storage of used motor oil and oil residues on port space
- Collection, management and disposal of waste (solid and liquid)
- Storage and handling of cargo

As for the built up land, the activities that could be initiated are related to the construction of new buildings within the sea port boundaries.

Based on the above analysis, following objectives should be prioritized in the environmental plan of Limassol sea port:

*Electricity consumption related objectives*
- Implementation of energy saving measures
- Building shell energy upgrade
- Replacement of building services
- Replacement of electromechanical building equipment
- Harvesting and exploitation of renewable energy
- Maintenance of electrical equipment/network

*Fuel consumption related objectives*
- Regular maintenance of vehicles and machinery
- Regular maintenance of space heating equipment
- Replacement of sea port fleet vehicles
- Compliance with rules of proper loading/unloading of vehicles
- Controlled entry of vehicles within the port facilities

*Water consumption related objectives*
- Recycling and waste water management measures
- Water leakage detection measures

*Waste decomposition related objectives*
- Hazardous gas detection systems and alarm
- Disposal of recyclable waste, hazardous waste, electronic and electrical equipment to approved bodies for recovery/ management
- Disposal of liquid waste treatment plant and recycling
- Collection, segregation and proper management of solid waste

## 5. Conclusions

Sea ports are organizations that inevitably cause significant environmental impacts. The appropriate management of sea ports environmental performance is a subject that should be further considered and developed by means of the environmental management related studies. In this work, a novel approach was attempted with the aim to allocate the environmental objectives of an environmental management system of a sea port with the ecological footprint caused by its operation. The Global Footprint Network guidelines were applied to quantify the ecological footprint of Limassol sea port, a main cargo and cruise home port of the Mediterranean region. The results revealed the significance of the environmental impact of sea ports, as the caused footprint of the investigated port was twice as large, compared to the average footprint of the country in which the sea port is hosted. Furthermore it was found that the land use types that caused the greater footprint were the built up land, as well as the uptake land to accommodate the carbon emissions. Following this analysis, the findings of the ecological footprint were allocated to the relevant environmental objectives of the environmental management system of Limassol sea port. This task was performed in order to rationalize the environmental plan of the Limassol sea port, aiming to identify the environmental objectives of the port's environmental management system that should be considered as more important. Based on this approach, environmental objectives related to electricity, fuel, waste and water consumption were retrieved from the organizations EMS and identified as more significant.

In this study, the combination of the ecological footprint findings and the environmental management system objectives is the novel element introduced. Moreover the study's result clearly point out that the use of a resource accounting tool such as the EF is a valuable tool to quantify and reveal the significance of port environmental impact. But, the environmental impact exposed comes from specific port activities and points out the importance of explicit environmental objectives. These results tip on the importance of the EF analysis mainly for energy efficiency objectives enhancing a port's environmental strategic plan. The methodology and the findings of this study aspire to widen the practices based on which environmental management systems are established and developed.

The implications of this work to research in the further development of the EF methodology are manifold.

- This study revealed that the results of the EF analysis can be directly utilized by environmental management systems, providing in this way the development priorities of these systems
- It may also be concluded that a challenging field in the further development of the EF is its adaptation to existing environmental evaluation tools, widening in this manner the applicability of the methodology.
- As all major environmental management systems are based on standardized procedures, EF procedures and extracted indicators may also in future be formulated and concretized in a similar manner in standardized processes.
- This study was also one of the first of its kinds for delivering the EF of a major sea port, which was the subject of this study. A similar approach can be applied for other groups of organizations, as well as for other categories of systems and products.

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