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Ecological Footprint Analysis of the Port of Thessaloniki as a tool for an Environmental Management System

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Abstract

Ports exert complex and highly significant impacts in the air, sea and land environmental components, including pollution, habitat degradation, biodiversity loss, and impacts on human health. The Ecological Footprint (EF) methodology is a tool of growing popularity that assesses the CO_2 emissions-related environmental impact. Within a broader Environmental Management System, the EF can provide a simple index to inform policy decisions. However, only a few studies have applied the EF methodology at ports. In this study the EF methodology was employed in order to assess the CO_2 emissions-related EF of the port of Thessaloniki (THPA), a mid-sized cargo and passenger port in Northern Greece, for two consecutive years, 2008 and 2009. The activities of the port were divided into six components: built-up land, population (port staff), electricity consumption, fuel consumption, solid waste production and wastewater production. THPA's total EF was higher compared to the ports of other studies, mainly due to the higher electricity and fuel consumption and the fact that the Greek electricity sector has a higher CO_2 emission factor. The limitations of the EF when applied at ports are discussed and alternative tools, methodologies and frameworks are suggested for environmental management at ports.

Keywords: Port of Thessaloniki; Ecological Footprint; Environmental Management Systems; CO2 emissions assessment

1. Introduction

Ports play a significant role in the global economic landscape. Maritime transport accounts for more than 80% of the volume of global trade (Merico et al., 2017). Ports themselves are major sources for economic development through activities such as cargo handling, warehousing, passenger transportation, ship repair and in their vicinity, fishing and commercial business opportunities (Darbra et al., 2005; Darbra et al., 2009; Erdras et al., 2015; Puig et al., 2015; Wooldridge et al., 1999). As such, they also play a significant role in environmental degradation. 10-15% and 3% of global anthropogenic SO_x+NO_x and CO_2 emissions, respectively, are associated with the maritime transport sector (Bjerken & Seter, 2019). Merico et al. (2017) found that shipping emissions of particulate matter and NO_x at 4 Mediterranean ports (Patras, Brindisi, Venice, Rijeka) were comparable to road traffic emissions, a relation that was even stronger regarding local SO_2 concentrations. The port jurisdiction in the EU typically falls between 0.5-2 km on land and 5-10 km offshore, making it a complex landscape with far reaching consequences (Darbra et al., 2009). These environmental concerns can be broadly associated with land activities, sea activities as well as electricity and fuel consumption (Bjerken & Seter, 2019). More specific environmental aspects and impacts of activities at ports include: air emissions, marine pollution, ship generated pollution (air emissions, waste water, solid waste, oily waste, underwater noise, ballast water etc), risks from transporting and storing hazardous materials, extraction of marine sediment (dredging), coastal erosion, biodiversity loss, noise, odor etc (Darbra et al., 2005; Erdras et al., 2015; ESPO/EcoPorts, 2016).

1.1. Enviromental Management Systems

The concept of sustainability has become increasingly important for industry operations and in the context of ports is considered to be the effective integration of socio-economic needs with legal, technical and environmental components (Hou & Geerlings, 2016; Longo et al., 2015; Yun et al., 2018; Wooldridge et al., 1999). An effective tool for integrating these demands into port operations is an Environmental Management System (EMS). An EMS documents the management structure of environmental aspects and impacts and their continual improvement (Bjerken & Seter, 2019). The systematic and continuous steps are: policy development, objective planning, procedures and manual development, application, audits and review (Tselentis, 2008). An EMS can be established independently by any organization but there are three main standards with environmental management certification: ISO 14001 (International Organisation for Standardization 14001), PERS (Port Environmental Review System) and EMAS (Eco-Management and Audit Scheme) (Darbra et al., 2009; Puig et al., 2015). The common technique of EMS is the identification and assessment of environmental aspects and impacts in order to effectively create policy, procedures, informed monitoring and continuous improvement of environmental performance (Darbra et al., 2005; Puig et al., 2015). ISO 14001 defines an environment aspect as an element of an organization's activity that can interact with the environment whereas an environmental impact is any change to the environment resulting from the environmental aspect (Puig et al., 2015). There have been several initiatives to establish a succinct methodology to handle aspects and impacts. EcoPorts strives to exchange information and impact to increase environmental consciousness in European ports and terminals (Puig et al., 2015). SOSEA, the Strategic Overview of Significant Environmental Aspects, is commonly used (Darbra et al., 2005; Puig et al., 2015). More recently, Puig et al. (2015) suggested the TEAP, the Tool for the Identification and Assessment of Environmental Aspects in Ports. In order to do so the activities of the ports are identified, followed by their environmental aspects. The relationship between the activities and aspects is then established, criteria for defining significance and the weighting of the criteria are determined to finally connect the aspects to the criteria (Puig et al., 2015). The importance of gathering data, monitoring and establishing policy is reflected in the growing number of port specific environmental initiatives in the EU (Puig et al., 2015; Darbra et al., 2009).

1.2. Ecological Footprint

The Ecological Footprint (EF) is an indicator designed by Mathus Wackeinagel and William Rees in the 1990s, in order to track past and current human pressures exerted on the environment, focusing on CO_2 emissions (Lin et al., 2019; Mancini et al., 2016). It is an accounting system that compares the planet's regenerative capacity to the demand placed on it by human activities and waste in terms of available bioproductive land (Lin et al., 2019; Mancini et al., 2016). Standardized land use categories were established with the advent of the Global Footprint Network and include forest land, cropland, grazing land, fishing ground, built up land and CO_2 uptake land (Lin et al., 2019).

The EF methodology has grown in popularity, especially during the last years, because of its focus on CO_2 emissions and its resulting link with climate change, its relative ease of application and effective communication (Lin et al., 2019). However, only a few studies have applied the EF in ports (Erdas et al., 2015; Millan et al., 2010). This paper aims to investigate the applicability of the EF methodology in contributing to the assessment of the environmental impacts of ports as part of an EMS. The integration of the EF framework in the EMS of the port as an index to raise environmental awareness and inform policy making can contribute to the sustainable development of the ports. The research methodology has been applied to the port of Thessaloniki, in order to investigate the environmental impacts by assessing the CO_2 emissions-related EF for two consecutive years, namely 2008 and 2009. Furthermore, discussion also includes the EF methodology's limitations, as well as alternative tools and methodologies including simulation that can be used to assess the environmental impacts at sea ports.

2. Methodology

The Ecological Footrpint (EF) methodology was employed in order to assess the CO_2 emissions-related Ecological Footprint of the port of Thessaloniki (THPA) for the years 2008 and 2009. The activities of the port were divided into 6 components: built-up land (expressed in hectares), population (port staff), electricity consumption, fuel consumption, solid waste production and wastewater production. The methodology for the calculation of the EF is described in detail in Lin et al. (2019), where the quantity of each of the 6 components is multiplied with specific factors in order to estimate first the resulting CO_2 emissions and then the associated EF, expressed in terms of the hectares of the global average bioproductive area needed to supply the specific product &/or service (measured in global hectares; gha). The final EF is the sum of the EFs of the different components (Lin et al., 2019). The factors employed that were specific for the case of THPA are presented in detail in the footnotes of Table 1. The data used were publically available data retrieved from THPA (2020).

The port of Thessaloniki is a mid-sized cargo and passenger port located in Thessaloniki, in northern Greece; it is the largest port of the wider Macedonia region (ESPO, 2017; THPA, 2020). It has been in operation since antiquity (315 B.C.) and as a traded company since 2001 (THPA, 2020). It has a total land area of 1.5 mil. m^2, length of 3.5 km, 6 docks with total length of 6.2 km and 600,000 m^2 of storage areas (THPA, 2020). For the period of study (2008-2009) it handled annually on average 2,076 ships (of which 93 % of 50-200 m length), 160,841 passengers, 15,502,528 t of cargo, of which 52% liquid cargo (mainly crude oil and oil products), 25% solid cargo and 23% containers (254,561 twenty-foot equivalent units (TEUs)) (THPA, 2020).

THPA is particularly active in the field of environmental management. It has been a member of the European Sea Ports Organization's (ESPO) "EcoPorts", which the main environmental initiative of the European port sector, since 2003 (ESPO, 2017). It was also accredited with the PERS certification, which is the EMS certification issued by ESPO's EcoPorts, from 2003 until 2014 (ESPO, 2017). Since October 2015 it is certified with the most common international EMS, ISO14001:2004 (ESPO, 2017).

According to THPA's current Environmental Policy Statement, the port's main environmental goals are: the application of ISO14001:2004 and of the relevant environmental legislation; the improvement of the performance of their EMS; the reduction of the environmental impacts related to port activities; the prevention of pollution; and detailed environmental monitoring and raising environmental awareness for their staff, business partners and passengers (THPA, 2020).

3. Results and Discussion

THPA's EF for the different components (build-up land, population, electricity consumption, fuel consumption, solid waste and wastewater) and for the two consecutive years, 2008 and 2009, are shown in summary in Figure 1 and Table 1. The 6 different components and the total EF of THPA are discussed below, with comparisons to the findings of Erdas et al. (2015) for the Limassol Port in Cyprus, due to the similarities shared by the two ports.

The EF of build-up land (584.4 gha) was similar to that calculated by Erdas et al. (2015) for Limassol Port (586.3 gha), due to the similar size of the two ports.

The EF of port staff (379.4 gha in 2008 and 358.9 gha in 2009) was 2.4 times more than that reported by Erdas et al. (2015) (153.1 gha) because the staff of THPA (570) is more than double that of Limassol port (242) and the per capita EF for Greece (5.90 and 5.62 gha per capita in 2008 and in 2009, respectively) is higher than that of Cyprus (4.05 gha per capita in 2012) (Global Footprint Network National Footprint Accounts, 2019). It should also be noted that the population component considers only port staff and not the passengers visiting the port. If the passengers were included in the analysis, with 163,502 passengers in 2008 and 158,179 in 2009 (THPA, 2020) and assuming a 2 hour average stay at the port for each passenger, the EF of the population component would be as high as 27,587 gha in 2008 and 25,261 gha in 2009, so ca. 72 times higher than that reported (Global Footprint Network National Footprint Accounts, 2019). However, that would result in a large overestimation of the population component and the total EF of THPA.

The EF of the electricity and fuel consumption were estimated at 3,497.7 gha and 1,058.8 gha for 2008 and at 3,232.2 gha and 1,145.7 gha for 2009, respectively. Electricity and fuel consumption EFs were 7.4 and 3.4 times higher, respectively, than those reported for Limassol port in 2012 by Erdas et al. (2015) (457 gha and 320 gha, respectively) for two reasons. Firstly, THPA had a 3.7 times higher electricity consumption and a 2.4 times higher fuel consumption compared to the values reported for the Limassol port. This was expected because THPA handled a total of 16,041,842 t of cargo in 2008 and 14,963,214 t of cargo in 2009 (THPA, 2020), compared to the 3,500,00 t of cargo handled by Limassol port in 2012. Furthermore, heating fuel consumption is negligible in Limassol due to the high temperatures all year round, contrary to THPA which is in northern Greece. As a result, THPA's energy consumption was much higher, even though Limassol port receives relatively more passengers (1 million per year (Erdas et al., 2015)). Secondly, the Greek electricity sector has a higher CO_2 emission factor because of the use of lignite as the main energy source (emission factor of Greece 1.149 t CO_2 / MWhe compared to that of Cyprus at 0.874 t CO_2 / MWhe (Koffi et al., 2017)).

For the waste component, both solid and water waste resulted in small EFs of 14.0-15.7 gha and 1.0-1.3 gha, respectively. The amount of solid waste managed by THPA (607-682 t) and the resulting EF were approximately 16 times less than the values reported by Erdas et al. (2015) (8,100 t of mixed garbage and 2,100 t of sludge resulting to an EF of 239 gha). This was possibly related to the nature of Limassol port, dealing more with passenger rather than cargo ships. Regarding recycled solid waste, it should be noted that from 2010 mixed garbage of THPA was reduced to an average 40 % of their levels in 2008-2009, as a result of a more effective recycling policy (THPA, 2020).

Wastewater is an underestimated parameter for two reasons. Firstly, ships are legally allowed to throw their non-contaminated waste water into the sea, at 12 or (in some cases) at 6 nautical miles from land, following IMO's MARPOL International Convention for Marine Pollution (THPA, 2020). As a result, the sewage wastewater that THPA received from the ships was relatively low and highly variable, ranging from 790 m^3 in 2008 to 9 m^3 in 2009. Secondly, wastewater decomposition emits methane (CH_4) rather than CO_2, a much more potent Green House Gas with a Global Warming Potential (GWP) 25 times more than that of

CO_2 (IPCC, 2006; Walsh et al., 2009).

The total EF of THPA ranged from 5,535.6 gha in 2008 to 5,338.0 gha in 2009, with electricity consumption accounting for 62 % and fuel consumption for 20 % of the total EF of the port (Figure 1, Table 1). The values of the EF between the two years, 2008 and 2009, were not statistically different (ANOVA test, $p<0.05$). THPA's total EF was higher when compared to the findings of Erdas et al. (2015) for the port of Limassol in Cyprus in 2012 (1,442.7 gha) and of Millan et al. (2010) for the port of North Coast and the port of Gijón in Spain in 2006 (5,125.8 gha and 7,366.2 gha, respectively, but 57.5 % accounting for the construction materials' embodied energy). This was mainly due to the higher electricity and fuel consumption of THPA, combined with the fact that the Greek electricity sector has a higher CO_2 emission factor because of the use of lignite as the primary energy source (emission factor of Greece 1.149; Cyprus 0.874; Spain 0.440 t CO_2 / MWhe (Koffi et al., 2017)).

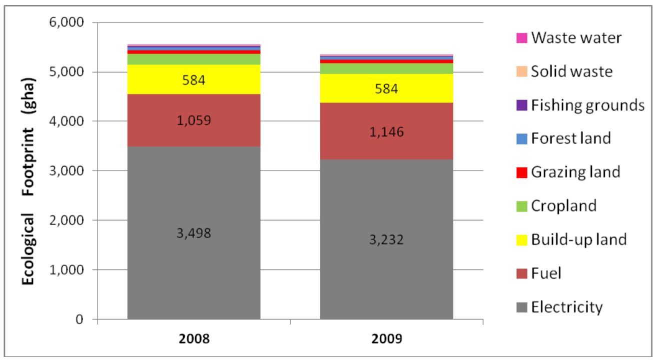

Figure 1. The EF of the Port of Thessaloniki (THPA) for 2008 and 2009.

Table 1. The Ecological Footprint (EF) of the Port of Thessaloniki (THPA) for 2008 and 2009. The term "Ecological Footpint" refers to the CO_2 emissions (excluding emissions of other GHGs and other types of environmental impacts of port activities) that are directly managed by THPA (excluding the emissions from ships, the population component of the passengers visiting the port and the activities of lessees of port premises). The initial port data are also shown (THPA, 2020).

	Port data		EF (gha)	
	2008	2009	2008	2009
Build-up land [a]	232 ha	232 ha	584.4	584.4
Population (port staff) [b]	570	570	379.4	358.9
Cropland	-	-	223.3	209.7
Grazing land	-	-	69.9	71.9
Forest land	-	-	63.3	55.3
Fishing grounds	-	-	22.8	22.1
Electricity consumption[c]	11,791 MWhe	10,896 MWhe	3,497.7	3,232.2
Fuel consumption [d]	1,294 t	1,400 t	1,058.8	1,145.7
Solid waste production [e]	607 t	682 t	14.0	15.7
Wastewater production [f]	7,618 m³	5,775 m³	1.3	1.0
Total EF of THPA	-	-	5,535.6	5,338.0

[a] All port premises (land, and marine area between breakwaters).
[b] Per capita EF for Greece as in Global Footprint Network National Footprint Accounts (2019), assuming eight-hour shifts for the port staff.
[c] Emission factor for consumed electricity in Greece: 1.149 t CO_2/MWhe (Koffi et al., 2007).
[d] Diesel oil for transport and heating. Emission factors: 3.186 t CO_2/t fuel for stationary applications (IPCC, 2006) and 3.164 kg CO_2/t fuel for transportation (DEFRA & DECC, 2010).
[e] Mixed garbage received from ships and produced at the port by passengers and staff, and recycled waste (tires, lubricant oils, batteries, electronic equipment). Mixed garbage % composition as in IPCC (2006) (values for Eastern Europe); % carbon content of the different waste categories as in IPCC (2006) and Herva et al. (2010); garbage produced at port: assuming a 3 kg/person/day solid waste production rate (THPA, 2020).
[f] Oil wastewater and sewage wastewater received from ships, and sewage wastewater produced at the port by passengers and staff. Calculated as in IPCC (2006); wastewater produced at port: assuming a 0.14 m³/person/day wastewater production rate (THPA, 2020).

Finally, it should be stressed that the methodology employed faces specific limitations, as only the activities that were directly managed by THPA were included in the analysis. The activities excluded were: (a) the fuel consumption of the ships when entering, exiting or docking at the port, (b) the population component of the passengers visiting the port and (c) all the activities related to lessees of port premises (e.g. museums, cafes etc). However, the emissions of the ships play a dominant role and greatly affect the wider area of ports (e.g. Bjerken & Seter, 2019; Merico et al., 2017; Tzannatos, 2010). Especially for the case of THPA, it is located in the city center of a city of 1 million inhabitants and had 2,225 and 1,926 ship arrivals in 2008 and 2009, respectively, of which 93 % were 50-200 m in length (THPA, 2020), negatively affecting the air pollution levels of the city (Saraga et al., 2019). Moreover, as discussed above, adding the passengers' population component in our analysis would increase it by 72 times and render it the main driver of the EF, accountable for 83 % of THPA's total EF.

Regarding the use of the EF, although it has been gaining popularity especially over the last years, it has been heavily criticized. While the easily interpreted indexes like the EF are appealing to managers implementing social corporate policies and making marketing statements, many argue against its value. Its definition, methodology, transparency, measurement, data collection and results have been criticized (Galli et al., 2016; Giampietro & Saltelli, 2014).

The major limitation of the EF is that it is an oversimplification and an underestimation of the whole spectrum of environmental impacts, despite its name as an "ecological" footprint. First of all, the EF methodology refers only to CO_2 emissions (Lin et al., 2019; Mancini et al., 2016). It omits the emissions of other highly potent GHGs, like methane (CH_4) and nitrous oxide (N_2O) (e.g. Walsh et al., 2009). Secondly, port activities are directly linked to a wide spectrum of environmental impacts of paramount importance, such as: (a) air, water and soil pollution with other pollutants beyond GHGs, some of which are highly toxic and persistent or linked to eutrophication, (b) pollution with marine litter (c) land and underwater noise pollution (d) severe underwater habitat degradation etc (e.g. ESPO/EcoPorts, 2016). Thus, the presence and the activities of a port can greatly affect the wider area and result in an impacted marine ecosystem and health concerns for the neighboring population (e.g. ESPO/EcoPorts, 2016). This is especially true for THPA because it is located in the semi-closed, shallow and sediment rich Thermaikos

Gulf and in the city center of Thessaloniki (Saraga et al., 2019).

4. Conclusions

The THPA's EF for two consecutive years, 2008 and 2009, have been assessed. The activities of the port were divided into six components: built-up land, population (port staff), electricity consumption, fuel consumption, solid waste production and wastewater production. The total EF of THPA ranged from 5,535.6 gha in 2008 to 5,338.0 gha in 2009, with electricity consumption accounting for 62 % and fuel consumption for 20 % of the total EF of the port. The values of the EF between the studied years were not statistically different. THPA's total EF was higher compared to the ports of other studies, mainly due to the higher electricity and fuel consumption and the fact that the Greek electricity sector has a higher CO_2 emission factor because of the use of lignite as the primary energy source.

The authors suggest that a more appropriate methodology for assessing a true 'Ecological Footprint' of THPA or any other EU port would divide the impacts of port activities into air, terrestrial and marine components and incorporate well-established and legally-bounding methodology defined by the relevant EU environmental legislation (e.g. for the marine component, the Marine Strategy Framework Directive), in conjunction with the EMS framework of EMAS or PERS and suitable existing port-specific methodologies (e.g. EcoPorts, SOSEA, TEAP (Puig et al., 2015)). Simulation modelling has been successfully used to assess the performance of ports in terms of sustainability and environmental metrics by providing valuable insights to port authorities regarding environmental management and sustainable development of ports (Hou & Geerlings, 2016; Longo et al., 2015; Mamatok et al., 2019; Yun et al., 2018; Zhang & Huang, 2019). Simulation methods include system dynamics, object-oriented simulation modelling by ARENA software and T-ESEDRAS simulation modelling. Moreover, high quality empirical research is necessary to improve the relationship between research, policy and its implementation if environmental performance is to be improved in a meaningful way (Bjerken & Seter, 2019). Future research will explore the development of a simulation-based EF framework as a tool for performance evaluation of the environmental impacts and management practices of port activities.

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