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A joint implementation of ecological footprint methodology and cost accounting techniques for measuring environmental pressures at the company level

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Abstract

The aim of this paper is to provide a conceptual framework and a practical methodology for evaluating the environmental pressures associated with company production. The model is based on the joint implementation of the ecological footprint accounting framework and cost accounting techniques. The methodology of cost accounting is applied by companies to determine the monetary cost of their products. These techniques are adopted by business administrations in cases of complex production activities, where the presence of processes with loops and feedbacks, of large infrastructures and multiple outputs make normal cost assignment too simple to correctly quantify the final costs. This paper adapts such monetary techniques to the purpose of measuring not the economic but the environmental costs that are quantified thanks to the adoption of the ecological footprint accounting framework.

To test our model we have applied it to the evaluation of the ecological footprint of the Italian railways: a case study representative of a complex production chain in that it involves the environmental evaluation of a large network utility, characterized by joint production, by multiple outputs and by a great distance between initial environmental costs and final outputs. The results are shown in comparison with a previous analysis on the same subject.

Finally, the paper discusses major potentialities and limits of the joint implementation of ecological footprint methodology and cost accounting techniques.

Keywords: firm metabolism, ecological footprint, cost accounting, Environmental Activity Based Costing

1 Introduction

The aim of this paper is to provide a conceptual framework and a practical methodology for evaluating environmental pressures associated with company production. The model is based on the joint implementation of the ecological footprint accounting framework and cost accounting techniques. Cost accounting is applied by companies to determine the monetary cost of their products. Our study adapts such monetary techniques for the purpose of measuring not the economic but the environmental costs that are quantified thanks to the adoption of the ecological footprint methodology.

Until now ecological footprint applications for businesses have been fairly limited. Chambers and Lewis (2001) were the first to use such methodology as an aggregated eco-efficiency indicator at the corporate level. They analyzed the case studies of Anglian Water Services (the UK regulated part of the Anglian Water Group) during the years 1998/99 and Best Foot Forward in 1999/2000. Lenzen et al. (2002) introduced, for the first time, the input-output analysis to calculate the ecological footprint at the company level, focusing on the case of the Sidney Water Services.

Some studies have adopted ecological footprints to analyze agricultural production: among the earlier ones, Thomassen and de Boer (2005) and Van der Werf et al. (2007) focused on the dairy sector, Deumling et al. (2003) on the horticultural sector and, more recently, Stoeglehner and Narodoslawsky (2009) on the energy-crop sector.

Niccolucci et al. (2008) applied the ecological footprint to compare conventional and organic wine production systems in Italy. In their study, energy and material data are sorted by four production phases (agricultural, winery, packing, distribution) considered separately.

Cerutti et al. (2010) used the ecological footprint for a detailed analysis of a commercial peach orchard. Differently from previous studies, they considered not only the one-year field operations, but also the whole lifetime of the orchard. The calculation was conducted by studying six different orchard stages separately.

A systematic approach, able to analyze also the impacts of supply chains, has been presented by Wiedmann et al. (2009). The model, denominated Hybrid Life-Cycle-Analysis, is based on a combination of a bottom-up approach and a top-down Environmental Input-Output approach. This method provides total impact quantification because of its ability to consider both direct impacts, “those occurring within an organization”, and indirect impacts “those generated by an organization’s suppliers or partners” (Wiedmann et al., 2009): in other words such methodology can take into account the impacts embodied in all the purchases of the organization. The model has been applied to small businesses or agencies like the Highlands and Island Enterprise (Censa, 2009), the Waverley Borough Council (Censa, 2008), and the Scottish Parliament (Wiedmann, 2008).

Several authors have outlined the potentialities of the ecological footprint method to become an important tool in measuring industrial metabolism. One of the first and greatest advantages, stressed, among others, in a report by the European Parliament (2001), is its ability to aggregate the environmental pressures into a single unit of measure in a way no other tool can. Ecological footprint has further potential for approaching the issue of sustainability in reference to the overall carrying capacity of the planet (Burdick, 2005) and to be readily and easily understood by all that have an interest in a company’s environmental performance (Barrett and

Scott, 2001). Furthermore, the methodology illustrates the progress toward sustainability over time of a single industrial organization (Chambers and Lewis, 2001) as well as constituting an accurate benchmark to evaluate and compare similar companies (Sutcliffe et al., 2005). Finally, it can help the industrial system to adapt to regional/local natural limiting factors (Korhonen, 2003).

In spite of the broad diffusion of the ecological footprint method for territorial applications and its potentialities, until now this methodology has been applied to production in a limited number of analyses, usually regarding case studies characterized by simple production chains (Cerutti et al., 2010; Bagliani, Dansero, 2011).

In our opinion, in order to offer a correct methodology to afford environmental evaluation in case of complex and multi-utility organizations, the environmental accounting system of the ecological footprint needs to be harmonized with other management tools (Holland, 2003). The proposal, discussed in the present paper, is based on a joint implementation of ecological footprint and cost accounting. Section 2 presents the different methodologies: cost accounting, ecological footprint and their joint implementation. Section 3 describes an application of the method to a case study, while Section 4 shows and discusses the results. Conclusions are drawn in Section 5.

2 Methods

2.1 Cost accounting techniques

Cost accounting techniques have been introduced and adopted by business organizations since 1970 and progressively modified and improved (Culmann, 1973; Peyton Young, 1985; Salvadori and Steedman, 1990). The main aim of these methodologies resides in their capacity to assign economic costs to final output in a correct and coherent way in cases of complex production chains, characterized by joint production, presence of processes with loops and feedbacks and different outputs.

These techniques are useful whenever the productive activities generate not only direct but also indirect economic costs. The former typology of cost refers to those expenditures that can be directly assigned to the final output through a causal and unequivocal relationship. A classic example is the cost to purchase flour in order to produce bread: in this case the baker can directly allocate the money spent for each kilo of flour to the final output represented by the bread produced from that flour. On the contrary, the latter typology of cost regards all the cases when a direct assignment is not possible because of the complexity of the production process. To return to the previous example: there can be indirect costs if our baker uses the flour to produce not only bread but also several different kinds of biscuits or if he has to buy wood for the oven to bake all products characterized by different cooking times. In both cases it is not possible to directly allocate the cost to the final product: the causal relationship has to be deduced following the whole production chain along all the paths related to the different outputs.

Cost accounting techniques are able to calculate the final costs of a firm production by re-allocating all the inputs costs (including raw materials and other purchased inputs, labor costs and other services, transportation costs and depreciation of capital equipment) to each step of the production chain and, in the end, to final products or services. Thanks to these methodologies a company is able to establish the correct price of its final outputs also in the presence of very complex production lines and large infrastructures and equipment (as in the cases of telecommunications, transport and energy distribution).

Furthermore, cost accounting provides useful information to decision makers about the economic performance of single activities, production lines, operations and services: this is the reason why it is also called management accounting (Hongren et al., 2005). In contrast to financial accounting (which is focused on the overall results including liabilities), management accounting provides detailed reports on the use of single factors of production.

The Activity Based Costing (ABC) methodology used in the present work is an evolution of traditional cost accounting and represents, nowadays, the emerging foundation of cost management (Turney, 2005). It is based on the following considerations, holding true for every economic activity:

- each production process can be divided into single activities, defined as suitable combinations of people, methodologies and the environment, aimed at the provision of a service;
- each activity causes the consumption of different resources and, as a consequence, generates economic costs.

From these principles derives the idea to propose an accounting system based on the concept of activity to aggregate and distribute initial costs along the production chain and, finally, to allocate them to the final products.

ABC methodology prescribes a cost accounting system structured along the following phases.

1) Identification of the different activities along the whole production chain. These activities, also called cost centers, represent intermediate cost aggregations useful to follow the causal relationship of production in order to link the initial costs with final outputs. They do not necessary coincide with the organization chart.
2) Hierarchical ranking of the cost centers with respect to their causal relationship to final output. In this phase, a helpful distinction is usually made between auxiliary and productive cost centers: the latter refer to those activities related to production, such as manufacturing, marketing and sales while the former relate to those activities supporting

the productive ones, such as human resource services, direction and management, research and development.[1]

3) Recognition of all the elementary economic costs and their distinction in direct DC_i and indirect C_j costs.
4) Assignment of direct costs to final output, with Equation (1), where TC_F represents the total final cost, DC_F and C_F respectively the total direct and indirect cost assigned to final output, and i runs over the number of direct costs:

$$TC_F = DC_F + C_F = \sum_i DC_i + C_F \qquad (1)$$

5) Assignment of indirect costs C_j to the k-th cost centers that have directly caused them by calculating Q_{jk}, the amount of cost j that enters into the activity k, following Equation (2):

$$Q_{jk} = C_j \delta_{jk} \qquad (2)$$

where δ_{jk} is the cost driver (see next point).

6) Identification of the most appropriate cost driver δ_{jk} for each re-allocation from cost center j to cost center k, i.e. choice of the parameter expressing the amount of the activity j that has been used by activity k. Suitable choices of such parameters can focus on percentages of utilization of machinery and tools, number of hours dedicated to assistance services, monetary expenditure for gasoline consumption, number of kilometers produced by the car fleet.
7) Iterative re-allocation of the costs from the previous cost center to the next one closer to final output following the hierarchical ranking of phase 2. Equation (3) calculates C_k, the total indirect cost assigned to cost center k:

$$C_k = \sum_j Q_{jk} = \sum_j C_j \delta_{jk} \qquad (3)$$

where the sum over j regards all the cost centers that are upward with respect to activity k along the production chain, i.e. all those activities that have been used by cost center k.

Iterative re-allocation, for an indefinite number of re-allocations, is described by Equation (4):

$$C_F = \sum_n \sum_m \ldots \sum_k \sum_j C_j \delta_{jk} \delta_{k\ldots} \ldots \delta_{\ldots m} \delta_{mn} \delta_{nF} \qquad (4)$$

where C_F, as already seen, represents the total indirect cost assigned to final output.

[1] Note that the distinction between productive and auxiliary activities adopted by ABC is closely related to the classification in primary and supporting activities proposed in Porter's studies on value chain (Porter, 1985) but do not necessarily overlap because several primary activities can be classified as auxiliary such as logistics.

8) Calculation of the total cost of each final output by adding direct and indirect costs following Equations (1) and (4).

ABC methodology is particularly useful for evaluating network utilities, i.e. industrial sectors using large infrastructures difficult to duplicate, like railways, telecommunications networks, infrastructures for the distribution of water, gas and electricity. These industrial sectors are characterized by a significant organizational complexity and potentially high economies of scale (Economides, 1996). This implies a considerable gap between initial costs required to run such companies and their final products or services.

2.2 The ecological footprint accounting system

The concept of the ecological footprint was first introduced by Rees (1992) and further developed by Rees and Wackernagel (1994), Wackernagel and Rees (1996). During the last two decades, the initial methodology has become progressively generalized and standardized and a huge amount of literature has been written, reaching important scientific journals such as Nature (Rees, 2003) and PNAS (Wackernagel et al., 2002). Highly influential is also the biannual publication of the Living Planet Reports, reporting ecological footprint calculations for almost all countries since 2001 (WWF et al., 2000; 2002; 2004; 2006; 2008; 2010).

Nowadays the most advanced version of the methodology consists of a complete accounting system, called EFA (Ecological Footprint Accounting), centered on the quantification of renewable resource use. The ecological footprint "represents the critical natural capital requirements of a defined economy or population in terms of the corresponding biologically productive areas" (Wackernagel et al., 1999, p. 377). In other words, the ecological footprint related to a population or to the production of economic goods or services is the total area of terrestrial and aquatic ecosystems required to produce all the resources that have been consumed and to absorb all the waste that has been generated, using prevailing technology.

This indicator takes into account six different kinds of bio-productive areas: cropland, grazing land, forest, fishing grounds, built-up land, and energy land. This last surface accounts for the area of forest needed to sequester the CO_2 deriving from fossil fuel combustion related to energy production. These components can be aggregated depending on research purposes. The most common distinction is between energy and non-energy footprints. Such division distinguishes between the use of natural capital services such as CO_2 absorption and biomass production.

The ecological footprint's unit of measure, for all the six types of bio-productive surface, is the global hectare (gha), representing one hectare of ecologically productive land with world average productivity.

The EFA methodology, because of its focus on renewable resources utilization, is not able to take into account several other components of environmental impact such as: contamination by radioactive materials, pollution from heavy metals, persistent synthetic compounds and any other emission for which there are no ecosystem services with significant assimilative capacity. Furthermore, several critical discussions on EFA (among the others see Van den Bergh et al., 1999; Vieira et al., 2004; Nijkamp et al., 2004) have made it possible to better explore the limits and possibilities of this method. We do not discuss such criticisms here because the purpose of our paper is to demonstrate that EFA, as well as other tools for measuring industrial metabolism, need to be implemented with a cost accounting technique.

Despite these weaknesses, the ecological footprint is a useful indicator, able to capture a considerable part of environmental pressure both on the input side (extraction of renewable resources) and on the output side (CO_2 sequestration and waste assimilation). This wide-ranging view is particularly significant and helpful in analyzing the environmental impacts generated by production activities.

2.3 A joint implementation of ABC and ecological footprint accounting: the Environmental Activity Based Costing

The idea developed in our research and described in the present article regards the joint implementation of ABC and ecological footprint methodology for the purpose of accounting not for the economic but for the environmental costs derived from production activities.

Our main aim is to provide both a conceptual framework and a practical methodology to calculate the final environmental impact associated with firm production. The harmonization of the concept of ecological footprint, able to quantify in a coherent way the anthropogenic demand on ecosystems, and the ABC accounting system, allows us to propose a methodology useful in cases of complex production chains, large infrastructures and multiple outputs.

In our joint implementation we use a component-based approach to calculate the initial environmental costs in terms of the ecological footprint, since we relate consumption of land to key activities. Our methodology is similar to the method (EcoIndex™) developed by Chambers and Lewis (2001), but it differs from that because it follows the causal relationship along the whole production chain.

Following phases 1 to 8 of Section 2.1, it is possible to define the main framework of an Environmental Activity Based Costing (EABC): after the identification of the different activities along the whole production chain (phase 1) and their hierarchical ranking (phase 2), an important phase (3) is the recognition of all the elementary environmental costs (resource withdrawal, use of energy, pollutant emissions, waste production, land needed to host buildings and infrastructures, etc.) and their distinction in direct and indirect costs. All these environmental costs are quantified in terms of the ecological footprint (measured in global hectares), following the well-known methodology revised by Global Footprint Network (2009). Because of the existence of six different kinds of productive land, both direct DF_i and indirect F_j environmental costs are expressed as the sum of different land components with α running from 1 to 6:

$$DF_i = \sum_{\alpha} DF_{i\alpha} \tag{5}$$

$$F_j = \sum_{\alpha} F_{j\alpha} \tag{6}$$

The next step (phase 4) regards the straightforward assignment of direct environmental costs to final output. Previous applications of ecological footprint methodology to production activities (see Section 1) were usually focused on production chains characterized by low levels of complexity. In these cases the accounting procedure was considerably simpler because there were only direct environmental costs that could be easily and unambiguously assigned to final outputs without using any allocation techniques.

Problems arise when dealing with more complex productive structures, where indirect environmental costs are important: in these cases their direct allocation to final outputs can seriously compromise the correctness of the whole calculation because of the risk of wrong and incoherent assignments. To properly allocate indirect environmental costs to final output, EABC proposes that such costs be first assigned to the cost centers that have directly caused them (phase 5), followed by an iterative process of re-allocation of the indirect environmental costs from the previous cost center to the next one closer to final output following the production chain (phases 6 and 7). The last hierarchical iteration is the one assigning such indirect environmental costs to final output.

Calculation of the total environmental cost of each final output (phase 8) is performed by adding direct and indirect environmental costs following Equation (7):

$$TF_F = DF_F + F_F = \sum_{\alpha}\left(DF_{F\alpha}\right) + \sum_{\alpha}\left(F_{F\alpha}\right) =$$

$$= \sum_{\alpha}\left(\sum_{i} DF_{i\alpha}\right) + \sum_{\alpha}\left(\sum_{n}\sum_{m}\dots\sum_{k}\sum_{j} F_{j\alpha}\delta_{jk}\delta_{k\dots}\dots\delta_{\dots m}\delta_{mn}\delta_{nF}\right) \tag{7}$$

where TF_F represents the total final environmental cost, DF_F and F_F respectively the total direct and indirect environmental cost assigned to final output; where δ_{ij} are the cost drivers; where i runs over the number of direct costs, and where the sum over n regards all the cost centers that are upward with respect to final output; the sum over m regards all the cost centers that are upward with respect to activity n along the production chain; and so on.

3 Calculation

To test our model we have applied EABC to the Italian railways (Ferrovie dello Stato Group): a case study representative of a complex production chain, because it involves the environmental evaluation of a large network utility, characterized by joint production and multiple outputs (provision of services of freight transport, regional passenger transport and national passenger transport) and by a great distance between initial environmental costs and final outputs.

The main companies controlled by the Ferrovie dello Stato Group are Trenitalia and RFI, Rete Ferroviaria Italiana (Italian Railway Net). The former is responsible for passenger rail transportation over medium and long distances, as well as for goods transportation, while RFI manages the national railway infrastructure, mainly composed of the railway network, including also stations, buildings, and electrical installations.

Primary data has been taken from the 2008 sustainability report of the Group (Ferrovie dello Stato, Rapporto di sostenibilità 2008) and refer to year 2008. Also the RFI 2006 environmental report has been considered (RFI, Rapporto ambientale 2006). Tables 1 and 2 show, respectively, environmental input and final output figures.

Following Section 2.3, our calculation has identified the different activities characterizing the Italian railways provision of services (phase 1) and has hierarchically arranged them according to the causal relationship along the whole production chain (phase 2). Figure 1 shows the causal network linking initial environmental costs to the different intermediate cost centers to the final outputs. The hierarchical ranking of activities results in a four-layer structure, characterized by two levels of auxiliary cost centers, with the presence, respectively, of “building” and of “car and bus fleet” and “human resource services”, and also by two levels of productive cost centers, with the presence, respectively, of “rolling stock” and of “passenger rolling stock”, “cargo rolling stock” and “infrastructure”.

The analysis of all the elementary environmental costs connected to the Italian Railway’s activities (phase 3) results in the recognition of five different typologies of costs, reported in Table 1 and shown in Fig. 1: “space occupation”, “energy consumption”, “water consumption”, “environmental impact of equipment” and “waste production”. All these environmental costs have been converted in global hectares of the ecological footprint following standard methodology and using the most recent conversion factors and equivalence factors (Global Footprint Network, 2009) as specified in the following.

Degraded land occupied by the various infrastructures (power stations and railway lines) was always considered. Railways length was converted into surface area on the basis of information from comparable European operators, by using an average railway line width of 4.17 m, corresponding to the real average width of 2.17 m plus a further occupation of 2 m between railways lines.

Energy footprint, related to fossil fuel combustion, was estimated by using a value of the Footprint Intensity of Carbon of 0.286 gha (t CO_2)$^{-1}$ yr^{-1}, derived from the National Accounts provided by Global Footprint Network. CO_2 emission caused by oil combustion was quantified on the base of a value of 0.073 t CO_2 / Gj (Anglesio, 1998), while CO_2 emission related to electric energy production was estimated by the authors by taking into account the 2008 Italian national electrical mix (Ministero dello Sviluppo Economico, 2008), resulting in a value of 0.057 gha/Gj.

Water consumption was translated into ecological footprint by using the value of embodied energy of 0.0005 t CO_2 / m^3, derived on the base of data of the Italian water services utility SMAT (SMAT, 2007).

The environmental impact of equipment was calculated by taking into account only the embodied energy related to passenger and cargo rolling stock. An average weight of 50 t and a useful life of 25 years were assigned to both passenger and cargo carriages. The ecological footprint quantification was performed by using the values of World Electricity and Heat Carbon Intensity of 0.50 Mt CO_2 TWh^{-1} and of Footprint Intensity of Carbon of 0.286 gha (t $CO_2)^{-1}$ yr^{-1}, derived by the National Accounts provided by Global Footprint Network.

Ecological costs related to waste treatment were calculated based on (Contu, 2002) one of the more exhaustive calculations of the ecological footprint of waste in Italy.

None of these environmental costs can be assigned directly to final outputs (phase 4): they are all indirect costs. Any attempt to attribute them directly to final outputs would result in an inaccurate or even erroneous quantification of the ecological footprint related to the transport services provided by Italian railways. For example, the environmental costs related to “electric energy for other uses” cannot be causally linked directly to final outputs because there is no information able to establish such a connection. Furthermore, even the costs derived from “electric energy for traction”, that can appear more directly related to final output, need to be accounted for through the EABC methodology because it is not possible to assign them to final outputs in a coherent way: in this case, final outputs are expressed in different units of measure (gha (million pass km)$^{-1}$ for “passenger national transport” and “passenger regional transport” and gha (million ton km)$^{-1}$ for freight transport) and there is no way to allocate the energy for traction proportionally with respect to two different quantities and units of measure. Furthermore, a direct assignment of initial environmental costs related to energy to final outputs would result in a constant proportion of the different energetic consumptions (electric energy, oil, gasoline) for all the final outputs, while such proportions are different and vary depending on the different path followed along the production chain to obtain the final output.

To correctly account for these indirect costs, EABC prescribes that a first assignment should be made to the cost centers that have directly caused them (phase 5). Yellow arrows of Figure 1 show such allocations. Because of the straightforwardness of each attribution, there was no need to use drivers. “Space occupation” environmental costs were distinguished between the surfaces related to building extension, assigned to cost center “building”, and those regarding the infrastructure network, attributed to “infrastructure”. “Energy consumption” costs were attributed to cost centers “car and bus fleet” (gasoline), “human resource services” (electric energy for illumination and oil for heating) and “rolling stock” (electric energy and oil for traction). “Water consumption” is related to civil and industrial uses: it was assigned to human resource services and infrastructure cost centers according to the utilized amounts. “Environmental impact of equipment”, representing the energy and material flows embedded in rolling stocks, was ascribed to “passenger rolling stock” and “cargo rolling stock” depending on the number of carriages and cargo wagons. Finally “waste production” was allocated to “building” and “infrastructure” as a function of the amount produced by the two cost centers.

Phases 6 and 7 are the core of the EABC allocation methodology because they regard the procedure of iterative re-allocation of the indirect environmental costs from the previous cost center to the next one closer to final output following the four hierarchical levels recognized in phase 2. In our case study, we have performed the re-assignments summarized in the following list.

1) The first hierarchical layer consists of only one auxiliary cost center, “building”. It was re-allocated (light blue arrows of Fig. 1) to “infrastructure” and “human resource services” on the basis of the attribution of civilian and industrial buildings that we estimated in equal parts (driver labeled as δ1 in Fig.1).
2) The second level contains two auxiliary cost centers that were re-assigned (light blue arrows of Fig. 1) in the following way.
    - “Car and bus fleet” was re-allocated to “rolling stock” and “infrastructure” according to the following basis: car to infrastructure, bus fleet to rolling stock (driver δ2 in Fig.1).
    - “Human resource services” was re-allocated to “infrastructure”, “passenger rolling stock” and “cargo rolling stock” on the basis of direct labor dedicated by “human resource services” to infrastructure, to passenger transportation and to freight transportation; the final percentage were respectively 41.4%, 42.6%, 16.0%, (driver δ3 in Fig.1; Table 3).
3) The productive cost centers of the third hierarchical level comprises only “rolling stock”, that was attributed (dark blue arrows of Fig. 1) to “cargo rolling stock” and “passenger rolling stock” using as the driver the number of rolling stock dedicated to passenger transportation and to freight transportation; the final percentages were 84.1% and 15.9% (driver δ4 in Fig.1; Table 3).
4) The last (fourth) level includes the re-allocation (dark blue arrows of Fig. 1) of the following three productive cost centers.
    - “Infrastructure” environmental costs were allocated to final outputs on the basis of their respective uses corresponding to the averaged share of the infrastructure. The driver is expressed in train km, a unit of measure that corresponds to a movement of a train over a distance of one kilometer; the final percentages were 24.4% for national passenger transport, 56.6% for regional passenger transport and 19.0% for freight transport (driver δ5 in Fig.1; Table 3)

- “Passenger rolling stock” was attributed to the corresponding final outputs (“national passenger transport” and “regional passenger transport”) on the basis of the passenger kilometer related to national and regional transport; the final percentages were respectively 51.5% and 48.5% (driver δ6 in Fig.1; Table 3)
- “cargo rolling stock” was allocated to the final output “freight transport”.

Thanks to the whole set of re-allocations above described it was possible to correctly quantify the final demand of bioproductive area related to the use of one unit of the different services provided by Italian railways: passenger national transport, passenger regional transport and freight transport.

4 Results and Discussion

Initial, intermediate and final figures related to environmental costs are illustrated in Table 4; it shows the initial values of the ecological footprint related to ecosystem resource consumption, their re-allocation to cost centers of levels 1 to 4 and their ending assignment to the final outputs.

Final results of EABC application to Italian railways are shown in Fig. 2 and Table 5, illustrating the ecological footprint values normalized to final outputs, i.e. to one unit of transport service. The highest value regards the freight transport, where the transfer of one ton of goods for one million of kilometers uses 98.2 gha (million ton km)$^{-1}$. Much lower values are related to the transfer of one person for one million of kilometers at the national level (28.9 gha (million pass km)$^{-1}$) and at the regional one (21.5 gha (million pass km)$^{-1}$).

Fig. 3 illustrates that the greatest percentage (from roughly 58% up to 85%) of the ecological footprint is caused by energy consumption (mainly electric energy), corresponding to energy land use, for all three outputs; while the second component is represented by the management of the waste in landfill (from roughly 25% up to 35%) for passenger transport, and by the equipment (12%) for freight transport. The remaining environmental costs related to water consumption and space occupation play a secondary role, accounting only for less than 1.5% of the total environmental costs.

The comparison of our results with those reported by Chambers et al. (2000) confirms a significant similarity with regard to the ecological footprint of passenger transport. Their calculation shows a value of 30 gha for the transfer of one person for one million of kilometers, quite close to the results obtained in the present study.

Figures related to freight transport show, however, a greater difference, because the value arrived at by Chambers et al. (2000) is 10 gha (million ton km)$^{-1}$, almost one order of magnitude smaller than our. The difference can probably be explained considering that the analysis by Chambers and collaborators took into account only trains using oil, while our calculation has considered the correct mix of energy input, characterized by a partial use of oil and a much more land intensive utilization of electric energy.

It is also possible to consider some of the most important studies on the impact of freight transport present in literature (among the others see: Royal Commission on Environmental Pollution, 1994; Lawson J., 2007). These analyses are usually expressed in terms of CO_2 emission per unit of service. These figures, when translated into gha, show an interval of results ranging from 29 gha (million ton km)$^{-1}$ (Schoemaker and Bouman, 1991) to 5 gha (million ton km)$^{-1}$ (Environment Canada and Railway Association of Canada, 2005). The value calculated using EABC methodology is higher when compared to this range, because of several factors: first of all, it includes not only the energy consumption contribution but also several other components (space occupation, equipment, water, etc.) and, furthermore, the energy component takes into account the whole set of energy uses, including those not directly related to traction, such as office heating and illumination and car fleet activities.

Differently from some analyses of the ecological footprint applied to production (Niccolucci et al., 2008) the contribution of human labor was not included in our calculations because we chose to follow mainstream methodology and to include, among the environmental costs, the energy consumption for illumination and heating of Italian railways offices and the degraded land to host buildings for civilian use, but not the ecosystem inputs required for workers' sustenance (food and fiber).

The successfully application of EABC to Italian railways has shown the potentialities of the joint implementation of ecological footprint accounting and activity based costing techniques. A main positive point is the verification of the strength of EABC methodology to quantify, in a correct and accurate way, the environmental costs related to final outputs, also in the presence of highly complex production chains.

In spite of the formal complexity of Equation (7), in real applications the calculations are easily implemented on very simple software tools such as Excel or similar programs.

Some of the major limits and critical points of EABC framework can be summarized in the following points.

For highly complex and very large productive organizations (such as multinational companies or multi-utility organizations) the critical phase can be the exhaustive recognition of all the activities and the correct reconstruction of the hierarchical network characterizing the whole production chain.

The choice of cost drivers, although often straightforward, depending on simple factors such as percentage of utilization of a service (such as human resource service) or a tool (such as car fleet), in some cases can be difficult and even arbitrary.

Furthermore, application of EABC methodology is much more time and resource consuming than normal attributions of initial environmental costs directly to final output. For analyses involving simple case studies, such as the ones quoted in Section 1, focusing on products such as wine (Niccolucci et al., 2008) and peaches (Cerutti et al., 2010), or organizations such as Highlands and Island Enterprise (Censa, 2009), the Waverley Borough Council (Censa, 2008) and the Scottish Parliament (Wiedmann, 2008), the utilization of our method can be redundant. On the contrary, as already outlined, in cases of complex production chains, EABC is, to our knowledge, the only methodology able to guarantee the correctness of results where direct attribution fails. This is why EABC can be coherently used together with other models, such as the one developed by Barrett et al. (2008, 2009), which are able to calculate, in a rigorous way, all impacts connected to the supply chain, thanks to an environmental extended input-output analysis, but is less focused on the allocation of the environmental costs to the final output. In this sense we can say that the two methods are complementary.

Finally, the applicability of our method strongly depends on the existence of an adequate documentation of the environmental costs and the organization of production. Such information has to be provided by companies and organizations: in several cases scarcity of documentation can be a crucial weakness.

5 Conclusion

In this paper we have presented a joint implementation of the ecological footprint framework and cost accounting techniques for measuring environmental pressures at the company level. The proposed methodology, called Environmental Activity Based Costing (EABC), is helpful in case of complex and multi-utility production, where the initial environmental impacts cannot be directly related to the final outputs but need to be assigned to them through more sophisticated and accurate procedures.

To test the method we have successfully applied EABC to the Italian railways case study, a large network utility with a highly complex production chain, characterized by joint production and multiple outputs (provision of services for freight transport, regional passenger transport and national passenger transport) and by a great distance between initial environmental costs and final outputs. The paper examines the case study's final results and discusses the main potentialities and limits of the proposed EABC methodology.

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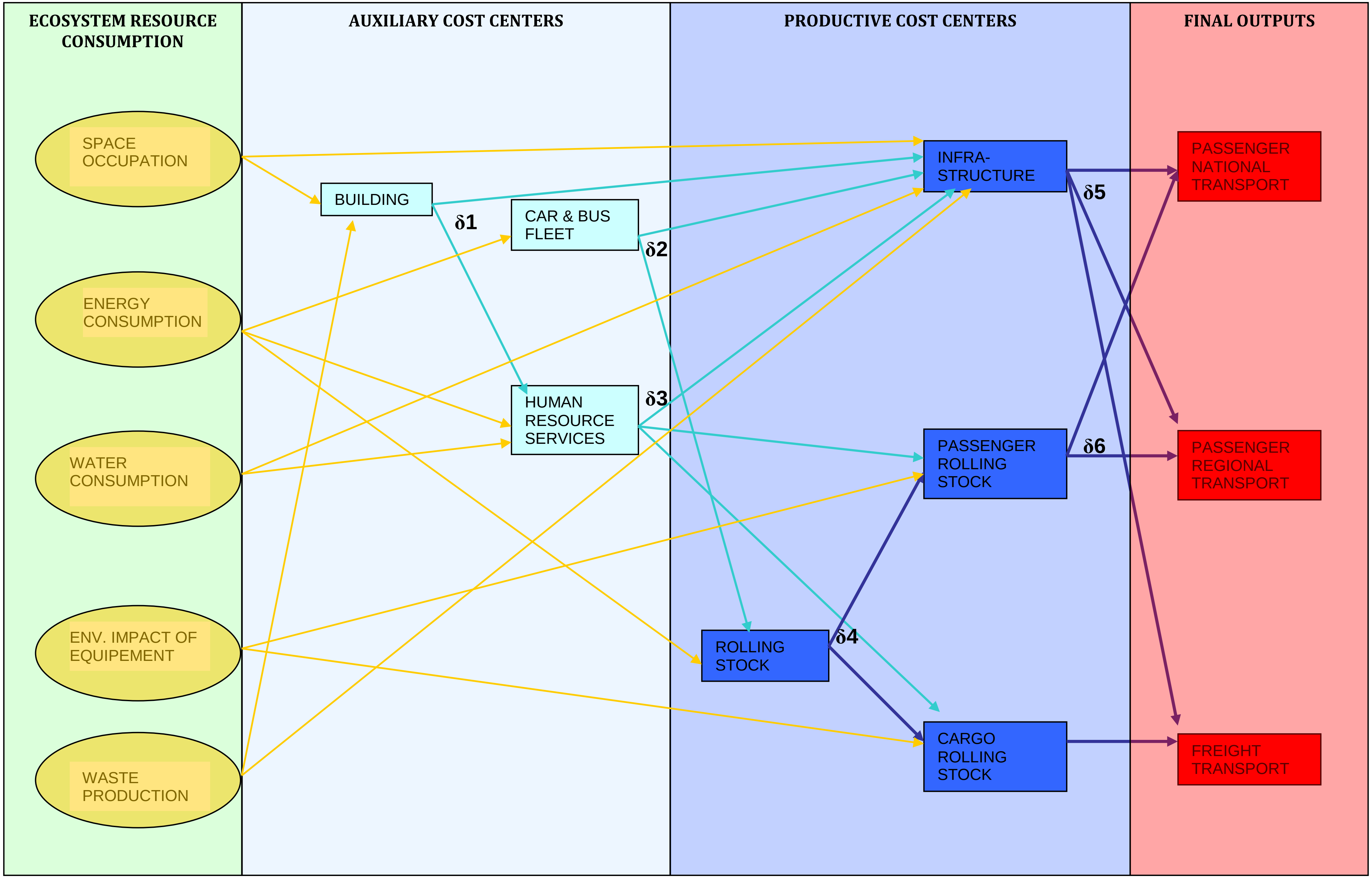
Figure(s)



ECOSYSTEM RESOURCE CONSUMPTION
AUXILIARY COST CENTERS
PRODUCTIVE COST CENTERS
FINAL OUTPUTS
SPACE OCCUPATION
ENERGY CONSUMPTION
WATER CONSUMPTION
ENV. IMPACT OF EQUIPEMENT
WASTE PRODUCTION
BUILDING
CAR & BUS FLEET
HUMAN RESOURCE SERVICES
δ1
δ2
δ3
INFRA-STRUCTURE
PASSENGER ROLLING STOCK
ROLLING STOCK
CARGO ROLLING STOCK
δ4
δ5
δ6
PASSENGER NATIONAL TRANSPORT
PASSENGER REGIONAL TRANSPORT
FREIGHT TRANSPORT

Figure 1. The causal network linking initial environmental costs to the different cost centers, to the final outputs. It is a four layers structure, characterized by two levels of auxiliary cost centers, and two levels of productive ones.

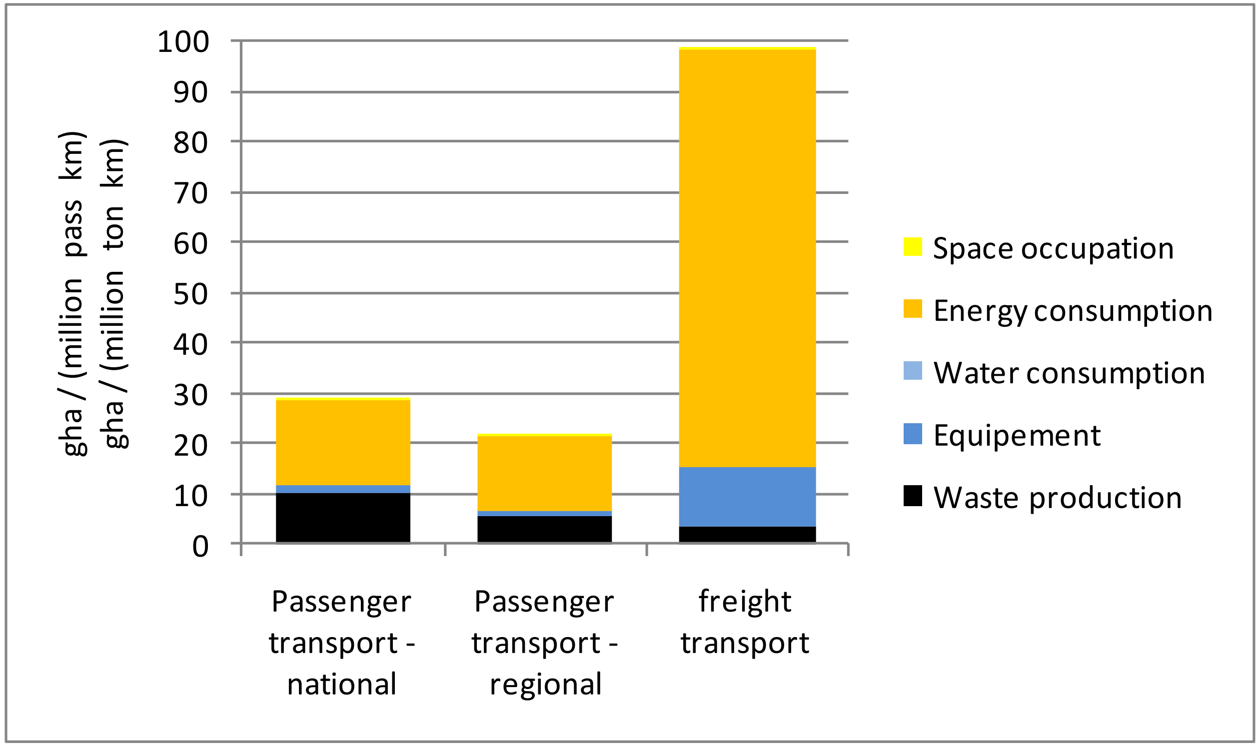


Figure 2. The ecological footprint associated to final outputs of the Italian railways.

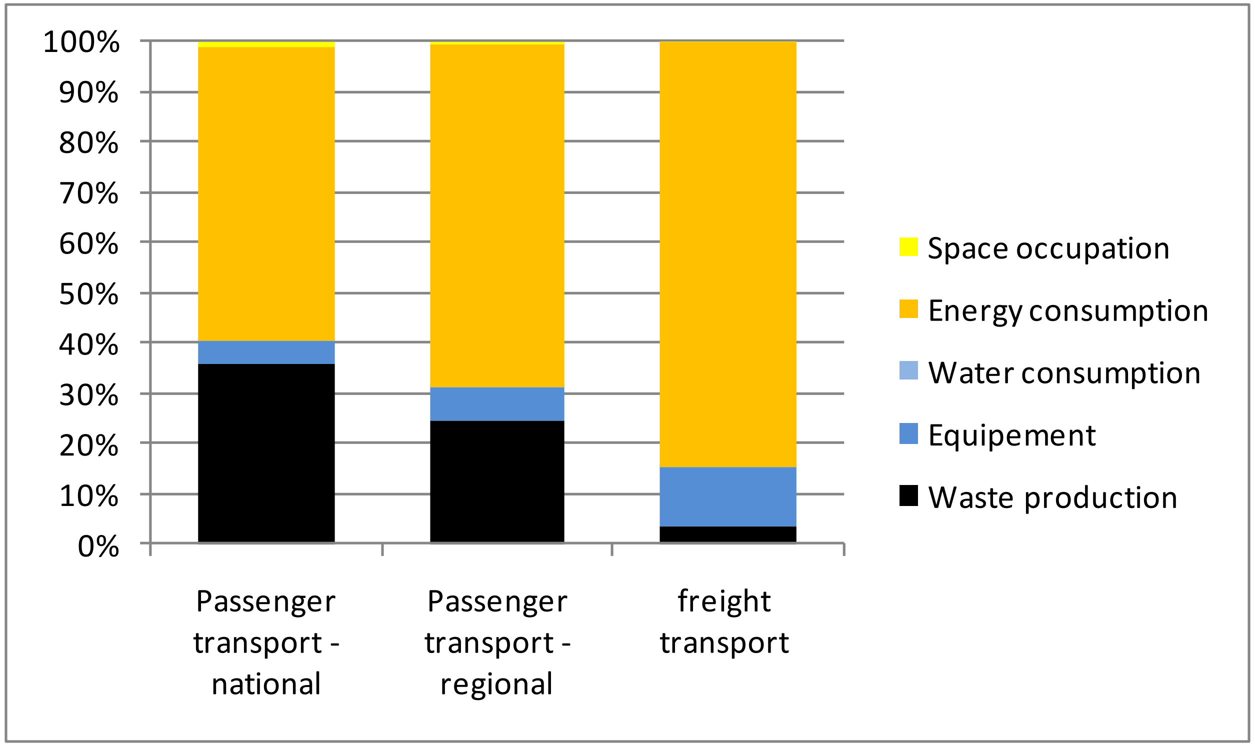


Figure 3. The ecological footprint associated to final outputs of the Italian railways in percentage.

Table 1. Italian Railways environmental inputs. Year 2008 and 2006. Sources: Ferrovie dello Stato, Rapporto di sostenibilità 2008; RFI, Rapporto ambientale 2006.

Environmental input	**Unit of measure**	**Value**
SPACE OCCUPATION		
Buildings	m^2	722,000
Infrastructures-lines	km	16,427
Infrastructures- tunnels	km	1,569
Infrastructures- bridges	km	590
ENERGY CONSUMPTION		
Electric energy for traction	TJ	44,677.29
Electric energy for other uses	TJ	6,074.04
Oil for traction	TJ	4,011.10
Oil for navigation	TJ	1,038.28
Oil for heating	TJ	1,552.01
Gasoline for car fleet	TJ	542.77
Gasoline for bus fleet	TJ	1,137.68
Total	TJ	59,033.17
Greenhouse gases related to passenger transport	CO_2 eq. – kton.	2,071.90
Greenhouse gases related to freight transport	CO_2 eq. – kton.	402.63
Total	CO_2 eq. – kton.	2,474.53
WATER CONSUMPTION		
Industrial uses	m^3	574,349
- of which waterworks	m^3	473,575
- of which strum	m^3	100,774
Civil uses (waterworks)	m^3	297,683
ENVIRONMENTAL IMPACT OF EQUIPMENT		
Rolling stocks – passenger	n.	7,840
Rolling stocks – goods	n.	41,316
WASTE PRODUCTION		
Recycling	ton.	215,000
Disposal	ton.	164,000
Total	ton.	379,000

Table 2. Italian Railways final outputs. Year 2008. Source: Ferrovie dello Stato, Rapporto di sostenibilità 2008.

Final output	**Unit of measure**	**Value**
Passenger transport (tot)	million pass km	45,766
- national transport	million pass km	23,586
- regional transport	million pass km	22,180
Freight transport	million ton km	28,125

Table 3. Cost drivers. Year 2008, source : Ferrovie dello Stato, Rapporto di sostenibilità 2008.

Driver	**Data used for the driver**	**Unit of measure**	**Value**
$\delta 3$	Personnel- staff	headcount eq	2,041
δ 3	Personnel- passenger	headcount eq	39,598
$\delta 3$	Personnel- goods	headcount eq	14,867
$\delta 3$	Personnel-infrastructure	headcount eq	38,501
$\delta 3$	Personnel- other activities	headcount eq	7,756
$\delta 4$	Rolling stocks – passenger	n.	7,840
$\delta 4$	Rolling stocks – goods	n.	41,316
$\delta 5$	Train km total passenger transport	thousand	268,442
$\delta 5$	Train km freight transport	thousand	62,839
$\delta 5$	Train km passenger national transport	thousand	80,956
$\delta 5$	Train km passenger regional transport	thousand	187,486
$\delta 6$	Passenger national transport	million pass km	23,586
$\delta 6$	Passenger regional transport	million pass km	22,180

Table 4. Initial values of ecological footprint related to ecosystem resource consumption; their intermediate allocation to cost centers of level 1 to 4 and their final assignment to final outputs.

	Ecological footprint
	gha
Ecosystem resource consumption	
Space occupation	15,569.59
Energy consumption	3,056,649.31
Water consumption	56.94
Equipment	394,354.88
Waste production	453,974.34
Intermediate allocation to cost centers of level 1 to 4	
Building	227,143.85
Human resource services	491,071.36
Car and bus fleet	34,847.84
Rolling stock	2,667,936.88
Infrastructure	570,614.56
Passenger rolling stock	697,579.00
Cargo rolling stock	2,652,411.50
Final assignment to final outputs	
Passenger transport - national	682,439.87
Passenger transport - regional	477,516.73
freight transport	2,760,648.46

Table 5. Ecological footprint values normalized to final outputs.

	Passenger transport - national	Passenger transport - regional	Freight transport
	gha / (million pass km)	gha / (million pass km)	gha / (million ton km)
Space occupation	0.4	0.2	0.1
Energy consumption	16.8	14.7	83.0
Water consumption	0.0	0.0	0.0
Env. impact of equipment	1.4	1.4	11.8
Waste production	10.4	5.3	3.3
Total	28.9	21.5	98.2