Carbon and water footprint accounts of Italy: A Multi-Region Input-Output approach

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ABSTRACT

This paper analyses the CO_2 emissions and the water use embodied in international trade in Italy. It is well documented that consumption of goods places a considerable strain on the environment and this phenomenon is further exacerbated by imports for domestic usage, which entail exploitation of water and environment. In this respect, the analysis focuses on the determination of Italian carbon and water footprints, which are two indicators able to determine how the human activities affect the environment, through the Multiregional and multindustry Input-Output model based on the World-Input-Output Database. The results show that CO_2 emissions and water use associated with Italian imports were greater than CO_2 emissions and water use associated with Italian export, mainly because the exploitation of resources in Italy is higher in the consumption phase than in production processes.

1. Introduction

The environmental exploitation and deterioration causing global warming and climate change have received a lot of attention at national and international level in the recent years. In particular, the environmental agendas of governments and international organisations focused on the increase in greenhouse gases (GHG) emissions and the water scarcity [1]. Indeed, the reduction of GHG emissions represents the worldwide target to be achieved in order to contain the global warming since the IPCC first assessment report was released in 1990 [2]. This document inspired the establishment of the United Nation Framework Convention on Climate Change (UNFCCC) that led to the ratification of Kyoto Protocol in 1997 [3]. This brought out the exigency to understand what activities generates GHG emissions and how they can be effectively reduced.

Focusing on the first aspect, in a context characterised by a significant growth of international trade it becomes crucial to take into account the contribution of trade to the global warming and climate change [4]. Indeed, it has been widely accepted that the increase in international trade has generated a significant growth in economic activities around the globe [5] and has changed the production and consumption perspectives, leading to a split of goods and services locations of production and consumption. Many production processes located in developed countries are purchasing goods and services from developing countries, which may results in the relocation of natural resources, energy use and pollution to developing countries [6]. Even though the Kyoto agreement has set clear targets to be achieved by each country, the contribution of international trade in GHG emission (or alternatively the shift of GHG emissions among countries) constituted a minor issue and it was not addressed in the discussion during the meeting. Nevertheless, the transformation of GHG emissions among countries and regions through international trade has become a relevant issue in recent time. The weight of global GHG emissions related to exports has reached the 30% of global emissions in 2013 [6] and this global trend is confirmed by several countries statistics on emissions [7–14].

Whereas the introduction of the Clean Development Mechanism (CDM) in the Kyoto Protocol as a tool to address the global emission was not effective [15], the traditional production-based approach of emissions accounting should be accompanied by a consumption-based approach. Following this line, emissions embodied in imports and exports should be considered in addition to the emissions generated from production activities within a country boundary to determine the amount of emissions directly and indirectly generated in a country [16]. Indeed, the international trade can be seen as an opportunity to implement the climate policy through a set of trade based mechanisms like border tax adjustments [17–19].

In this paper, we decide to follow the footprint approach that has the capability of ascertaining as to how the human activities weight on environment [20].

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The “carbon footprint” term and concept in particular, became widely used in the debate on responsibility and abatement actions against global climate change since a decade ago. Despite its popularity, this term does not have a definition or a methodology of calculation universally accepted, but the definition suggested by Wiedman and Minx [16] seems to provide a broadly answer to many criticisms. According to these authors “the carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product” [16]. This definition include only CO_2 in the analysis since many of the other pollutants are difficult to be quantified because of data availability. In addition, this definition refrains from expressing the carbon footprint as an area-based indicator allowing the more accurate representation in tonnes of carbon dioxide and including emissions generated through international trade.

Similar to the carbon footprint is the “water footprint” concept that was developed in recent years to provide a consumption-based indicator of water use [21]. Indeed, the unsustainable use and contamination of freshwater, also called the “water crisis” issue, has been considered another relevant threat not only to the health of ecosystem, but also to human societies and food security [1]. Water is a limited natural resource and during the last decades, its use has been increasing at more than twice the population growth rate [22]. The depletion of aquifers, the deterioration of water quality and rivers running dry are only some examples of the global unsustainable water resources management [23]. The water footprint is an important indicator introduced to provide a virtual measure of the water embodied in goods and services produced in one location. It can be defined as the water consumed to produce goods and services along the full supply chain [24] and lately it is widely used to measure the hidden links between human consumption and water use and between global trade and water resources management [25,26].

From a global sustainable development perspective, the growing water requirements to produce traded goods is not a minor issue, as well as the carbon embodied in imports and exports. More precisely, due to the increasing globalization and the growth of export of water-demanding commodities, the problem of water scarcity become even more complicated, prolonging the restraints for water scarcity beyond the national boundaries [26].

Therefore, both carbon and water footprint indicators provide a measure of environmental pressure, or better, the human use of resources and the anthropogenic GHG emissions into the environment related to the production and consumption behaviour of a country or region [27]. In particular, the carbon footprint is expressed in terms of mass units (e.g. kg or tons) of carbon dioxide (CO_2) or carbon dioxide equivalents emissions (for other GHG) per unit of time or per unit of product [20]. The water footprint is measured in terms of water volume (e.g. L or m3) per unit of time, or unit of product whose amount can be expressed in various way (e.g. L per kg, L per kcal, L per g of protein etc.) [28].

In this article, a special attention is devoted to CO_2 emissions and water use resulting from the relocation of production among countries as a consequence of international trade. In this context, a large number of models were developed to estimate environmental pressures embedded in international trade of several countries and regions. Environmental multisectoral models in particular, provide an appropriate methodological framework to complete environmental pressure estimation at national and international level. These models are commonly used to determine the footprints indicators from a top-down perspective [16] in macro and meso-systems and can easily identify the footprint of many agents operating in the economic system, such as industries in production processes and households and government in consumption processes [29]. In particular, there is a considerable literature supporting the use of Multi-Regional Input-Output (MRIO) tables in quantifying the carbon and water footprint and the incidence if international trade on them [30–33].

We concentrate on the Italian case and develop a quantitative analysis of the carbon and water footprints with a particular attention to the measurement of CO_2 emissions and water use embodied in international trade. Indeed, in the last decade, Italian Government paid a great attention to environmental issues and in particular, to the control of CO_2 emissions and to the sustainable use of fresh water, anticipating in many cases, the environmental policies set forth by the EU. Even if these efforts results in a reduction of carbon emissions (around −23% with respect to 1990) and water footprint, the Italian environmental policies should be developed in order to meet with the EU targets of 2020.

In this respect, we are interested in detecting what is the incidence of CO_2 emissions and water use related to international trade, in order to enlarge the possibilities for the policy maker, to develop effective environmental policies. For this purpose, we perform a detailed analysis on the emissions and water use embodied in Italian exports and imports according to the consumer approach using a new set of high-resolution global multi-region input–output (MRIO) tables.

The article is organised in six sections explaining the methodology adopted, the results of the analysis and some final considerations. In particular, Section 2 provides a brief review on MRIO models and their contribution on environmental analysis; Section 3 describes in detail the dataset and the MRIO model used in this study; Section 4 discusses the results of the analysis for the carbon footprint and Section 5 for the water footprint; Section 6 offers some final considerations.

2. Background on environmental multisectoral approach

The multisectoral approach is one of the most frequently used methodology in determining the environmental pressure of human actions and footprint indicators [16]. Environmental extended Input-Output models in particular, allows evaluating the different agents' contribution on pollution when operating in the economic system both from production and consumption side [34–36]. They provide a useful instrument to understand the incidence of international trade to environmental damages, or in other words, the phenomenon of carbon dioxide and water use burden-shifting among countries [37–39].

In this respect, two different approaches to the use of Environmental extended Input-Output model can be identified. In the first approach, the regional model considers the bilateral trade with respect to different economies and the embodied environmental pressures (i.e. emissions, land use, water use, energy use etc.) as exogenous variables [16]. In the second model, the multiregional approach, each domestic technical coefficient is combined with trade flow matrices to determine the intermediate flows matrix. The second type MRIO model is also known as the true or full multiregional model. Several studies used the single region I-O and MRIO models to measure water and carbon footprint for Australia [40], UK [41], New Zeland [42] and China [33]. In other cases, MRIO model was used to perform a structural decomposition analysis to understand the variations in the UK production and consumption carbon emissions during the period from 1994 to 2004 [43]. More recently, there are the contributions of Steen-Olsen et al. [44] and Ali (2017) [45] that used the MRIO model to assess three kind of environmental footprints for the EU member states. Arto, et al. (2012) [46] used a MRIO model to quantify the water demand for production and consumption and the water flows for 33 countries and the rest of the world.

3. Data and methodology used in the analysis

3.1. Data

The recently constructed World Input-Output Database (WIOD) [47] represents the main data source of this analysis. WIOD is indeed, considered the first database providing a detailed annual time series on national input-output tables and international trade and satellite accounts related to environmental and socio-economic indicators from 1995 to 2011 [48]. The WIOD database covers 27 EU countries, 13 other major countries in the world and a further region called "Rest of the world" as an aggregated region.[1]

In this study, we consider two sub-databases: the World Input-Output Tables (WIOTs) at current and previous year prices (35 industries by 35 industries) and the database on environmental accounts for the period from 1995 to 2009. The WIOTs has a dimension of 1476 rows and 1640 columns: the rows are headed to 1435 industry-country pairs (35 industries × 41 countries) and value added by country (1 × 41). The columns are headed to 1435 industry-country pairs (35 industries × 41 countries) and 5 components of final demand[2] by country (5 categories x 41 countries) for a total of 205 columns.

The data on satellite accounts are related to environmental and socio economic indicators, namely: emissions, energy, water, land, materials, value added and specific industry output, capital stock and investment, wages and employments by skills type. WIOTs data for CO_2 emissions and water includes 41 countries, 35 industries plus households for the period from 1995 to 2009. The statistical treatment of water accounts in the WIOD database is based on the concepts of water footprint approach [49].

3.2. Methodology

This study relies on the MRIO model based on the WIOD database, following the methodology described by Peters and Hertwich [32]. Using the traditional input-output model:

$$\mathrm{x} = \mathrm{Ax} + \mathrm{f} \tag{1}$$

the multi-region I-O equation can be written in the standard accounting balance of monetary flows [50] as:

$$\mathrm{x}^r = \mathrm{A}^r\mathrm{x}^r + \mathrm{f}^r + \mathrm{e}^r - \mathrm{m}^r \tag{2}$$

where $\mathbf{x}^r$ is the vector of total output, $\mathbf{f}^r$ is the vector of final consumption (i.e. expenditure by household, government and gross fixed capital - domestic and imported), $\mathbf{e}^r$ is the vector of total exports and $\mathbf{m}^r$ is the vector of total imports. $\mathbf{A}^r$ represents the matrix of intermediate consumption and its columns are the input from each industry (domestic plus imports) to produce one unit of output in each industry. This condition holds in each region, **r** and each industry. Following Ali, [45], in terms of bilateral trade, from region r to region s, it is possible to express total exports and total imports as:

$$\mathrm{e}^r = \sum_s \mathrm{e}^{rs} \tag{3}$$

$$\mathrm{m}^r = \sum_s \mathrm{e}^{sr} \tag{4}$$

Similarly, we can decompose the final consumption $\mathbf{f}^r$ and intermediate consumption $\mathbf{A}^r$ between its domestic and imported components as follow:

$$\mathrm{f}^r = \mathrm{f}^{rr} + \sum_s \mathrm{e}^{sr} \tag{5}$$

$$\mathrm{A}^r = \mathrm{A}^{rr} + \sum_s \mathrm{A}^{sr} \tag{6}$$

where $\mathbf{A}^{rr}$ is the industry requirements of domestically produced goods while $\mathbf{A}^{sr}$ is the industry requirements of imported goods from region s to region r.

Removing the imports from all components of the balance Eq. (2) we still have the same equilibrium condition but only in terms of domestic activities [48]:

$$\mathrm{x}^r = \mathrm{A}^{rr}\mathrm{x}^r + \mathrm{f}^{rr} + \sum_s \mathrm{e}^{rs} \tag{7}$$

Since we are interested in emphasizing a region's environmental pressure related to international trade, we extend the standard Input-Output analysis (IOA) framework by adding data on environmental pressures in physical units. Thus we calculate the direct environmental pressures (i.e. carbon, water use etc.) coefficients (p_j) which represent the shares of environmental pressure per unit of output in each industry j. It is calculated as the total amount of environmental pressure directly produced in the industry j by the total output of that industry, x_j. Using the above formulation, we can explicitly determine the environmental pressure embodied in trade in each region as:

$$p^r = \mathrm{P}^r\mathrm{x}^r = \mathrm{P}^r(\mathrm{I}-\mathrm{A}^{rr})^{-1}(\mathrm{f}^{rr} + \sum_s \mathrm{e}^{rs}) \tag{8}$$

where **I** is the identity matrix, $\mathbf{P}^r$ is a row vector representing the environmental pressure per unit of output, $\mathbf{A}^{rr}$ is the matrix of interindustry requirements of domestically produced products demanded by domestic industries, $\mathbf{f}^{rr}$ are the products produced and consumed domestically, $\mathbf{e}^{rs}$ are the exports from region r to region s. Therefore, p^r represents the environmental pressure related to the production of both domestic and exported products. It can be further decomposed into its components in order to obtain the environmental pressure related to domestic demand of domestic products in region r:

$$p^{rr} = \mathrm{P}^r(\mathrm{I}-\mathrm{A}^{rr})^{-1}\mathrm{f}^{rr} \tag{9}$$

and the environmental pressure embodied in trade (EPET) from region r to region s:

$$p^{rs} = \mathrm{P}^r(\mathrm{I}-\mathrm{A}^{rr})^{-1}\mathrm{e}^{rs} \tag{10}$$

The sum of Eq. (9) and Eq. (10) gives the total environmental pressure (EP) occurring in a specific country.

The total environmental pressure embodied in export (EPEE) from region r to the rest of regions can be calculated as :

$$p_e^r = \sum_s p^{rs} \tag{11}$$

The total environmental pressure embodied in imports (EPEI) into region r from the rest of regions is:

$$p_m^r = \sum_s p^{sr} \tag{12}$$

The difference between the indicators obtained in Eqs. (11) and (12) represents the Balance of Environmental Pressure Embodied in Trade (BEPET) :

$$p_{BEPET}^r = p_e^r - p_m^r \tag{13}$$

which shows the trade balance for environmental pressure (i.e. emissions, land use etc). Using the above formulation the production based environmental pressure inventory can be obtained as:

$$p_{production}^r = p^r = Domestic + p_e^r \tag{14}$$

where $p_{production}^r$ is the total domestic environmental pressure occurring from the production processes within a region. From the standard I-O analysis perspective, the consumption-based environmental pressure inventory can be determined as:

$$p_{consumption}^r = p_{production}^r - p_e^r + p_m^r = Domestic + p_m^r \tag{15}$$

where $p_{consumption}^r$ represents total global environmental pressure occurring from consumption within a country or region. It is important to note that if the total sum of EPEE (p_e^r) is equal to the EPEI (p_m^r) than the total $p_{production}^r$ corresponds to $p_{consumption}^r$.

This condition shows that, if we consider two different countries or

[1] See appendix A for complete list of countries and industries.

[2] The final demand of each country is disaggregated into 5 components: final consumption expenditure by household, Non-profit institutions serving households (NPISH), Government, Gross fixed capital formation and inventories.

regions with the same level of global environmental pressure, their internal composition can follow different accounting principles and apart from the domestic activities, environmental pressure related to trade might play a crucial role.

A full MRIO model is able to track the trade flows that goes to intermediate and final consumption. In this context, by decomposing exports in Eq. (7) we can get the main components in the MRIO model:

$$x^r = A^{rr}x^r + f^{rr} + \sum_{s\neq r} A^{rs}x^s + \sum_{s\neq r} f^{rs} \tag{16}$$

The above equation can be expressed in matrix form for each region as follow:

$$\begin{pmatrix} x^1 \\ x^2 \\ x^3 \\ \vdots \\ x^n \end{pmatrix} = \begin{pmatrix} A^{11} & A^{12} & A^{13} & \cdots & A^{1n} \\ A^{21} & A^{22} & A^{23} & \cdots & A^{2n} \\ A^{31} & A^{32} & A^{33} & & A^{3n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ A^{n1} & A^{n2} & A^{n3} & \cdots & A^{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{pmatrix} + \begin{pmatrix} \sum_r f^{1r} \\ \sum_r f^{2r} \\ \sum_r f^{3r} \\ \vdots \\ \sum_r f^{nr} \end{pmatrix} \tag{17}$$

4. Carbon footprint and trade in Italy

In the last twenty years, as a member of European Union (EU), Italy has embraced the European objectives on climate change and fixed binding targets to reduce the level of CO_2 emissions since the ratification of the Kyoto Protocol in 1998 [3,55]. In this respect, according to ISTAT data [52] on emissions, the level of CO_2 emissions in Italy declined by 23% from 1990 to 2014 in relation to both the production and consumption processes.

This result is encouraging in terms of climate change objectives, especially considering the ambitious targets of the European Union in terms of Climate Actions [53]. However, we are interested in examining more in depth the composition of Italian CO_2 emissions and the incidence of International trade on its trend in order to identify the most appropriate environmental policy measure to deal with the long term environmental targets. With this aim, using the MRIO model we determine the carbon footprint for the Italian economy keeping a particular attention to the disaggregation between emissions from consumption and production and between emissions embodied in exports and imports.

4.1. Major Italian CO_2 emissions indicators

According to the data reported in WIOD environmental database and the derived MRIO model, the total Italian carbon footprint increased from 1995 to 2005 around 19% reaching a level of 629. Million tons (Mt) CO_2-equivalents, which represents the 2.30% of the world total amount of emissions. As showed in Table 1, this trend reverses after 2005 and it is possible to observe a progressive reduction

Table 1
Italian CO_2 emissions embodied in domestic activities and global trade, 1995–2009.

CO_2 Emission (Mt)	1995	2000	2005	2009
Households Consumption	94.3	105.4	109.4	95.4
Intermediate Consumption	259.6	262.5	278.8	238.9
Emission Embodied in Export (EEE)	100.5	106.0	111.2	90.4
Emission Embodied in Import (EEI)	174.2	221.5	241.4	210.3
Production Base Accounts	454.4	473.9	499.4	424.8
Consumption Base Accounts	528.1	589.5	629.6	544.6
Balance of Emission Embodied in Trade (BEET)	−73.7	−115.5	−130.2	−119.9
EEE as % of Production	22.1%	22.4%	22.3%	21.3%
EEI as % of Production	38.3%	46.7%	48.3%	49.5%
Balance of Emission Embodied in Trade (BEET) as % of Production	−16.2%	−24.4%	−26.1%	−28.2%
Total Italian Carbon Footprint	528.1	589.5	629.6	544.6

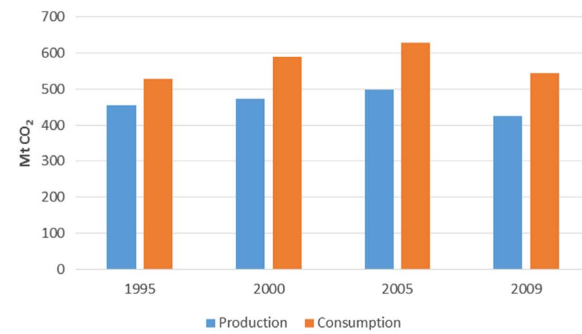

Fig. 1. Italian CO_2 emissions from production and consumption, 1995–2009.

in the carbon footprints of Italy as the policy maker increasing attention on environmental aspects. The total carbon footprint in 2009 recorded 544.6 Mt CO_2 equivalents, which represents the 1.9% of the total world carbon footprint.

Data reported in Table 1 are also displayed graphically to make easier the comparison of the results: in particular, Fig. 1 displays results of the analysis on production and consumption based emissions.

Over the period 1995–2009, the consumption based CO_2 emissions is always higher than the production based CO_2 emissions and both indicators reach a peak in 2005. In 2009 the production-based emissions was amounted to 544.6 Mt-CO_2 equivalents, which was about 6.5% lower than emissions in 1995 of 454.4 Mt-CO_2 equivalents. On the contrary, even if we observe a decreasing trend after 2005, the consumption-based emissions in 2009 are still higher with respect to the level of 1995 by 3.0%.

The significant reduction in consumption and production based emissions is originated by the combined effect of several causes occurring after 2005. Indeed, many studies argue that the reduction in CO_2 emissions registered in last decade is not only related to the higher attention of policymaker to environmental aspects, but can be mainly attributed to the reduction of production and consumption consequential to the global crises [51,52]. Nevertheless, in response to the economic crisis occurred in 2008, the Italian Government introduced a set of measures to boost a sustainable economic growth. In this respect, some environmental policy reforms were adopted such as the increase in fuel taxes, the introduction of incentives for energy efficiency and further liberalisation of energy, environmental and transportation services [54].

Focusing on carbon emissions related to international trade, it is possible to observe that the change in Emissions Embodied in Export (EEE) remained rather stable over the period 1995–2009 with a slightly reduction in 2009, as showed in Fig. 2. Indeed, from Table 1 we can notice that emissions embodied in export in 1995 was accounted for about 22.1% of production-based emissions, while in 2009 this amount reduced to 21.3%. On the contrary, the Emissions Embodied in Imports (EEI) have raised by 20.7% from 174.21 Mt-CO_2

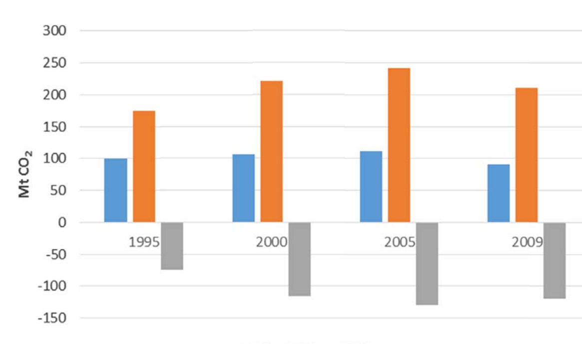

Fig. 2. Italian CO_2 EEE, CO_2 EEI and CO_2 BEET from 1995 to 2009.

equivalents in 1995 to 210.3 Mt-CO_2 equivalents in 2009. In particular, in 1995 EEI accounted for about 38.3% of production-base emissions and for about 49.5% in 2009. Therefore, even if the amount of EEE decreases in 2009 with respect to 1995, the level of EEI remains at a higher level with respect to the same year.

This effect is also emphasised by the trend of the Balance of Emissions Embodied in Trade (BEET) that represents the difference between production and consumption emissions accounts. In general, when the value of this difference is positive, it implies that the country is a net exporter of emissions, otherwise, for a negative value the country is a net importer of emissions. Looking at both Table 1 and Fig. 2, we can observe that Italy is a net importer of emissions throughout the whole period. More precisely, the BEET increases continuously from 1995 to 2005, where it reaches its peak of −130.2 Mt-CO_2 equivalents. Then it starts declining and in 2009 it reaches −199.85 Mt-CO_2 equivalents. The decline in the later year's level of EEI depends on the fall in consumption of Italian residents.

4.2. *Italian CO_2 emissions embodied in trade by country and by industry*

The database and the MRIO model allow determining the level of CO_2 emissions associated to international trade and disaggregated by 40 countries and 35 industries.

We firstly considered the CO_2 emissions embodied in trade with the Italian trading partner for the period 1995–2009. From Fig. 3, we can notice that most of the Italian EEI come from Russia, China, India and among the EU-27, Germany, Poland, Nederland, Bulgaria and Belgium.

In 1995 BEET from Russia accounted for about 7.6% of production-base emissions, by 2000 BEET grew more than 11.8%, making Russia the largest source of EEI. However, from 2000 there was a significant decline in the imports from Russia to 7.4% in 2009. BEET with China, Germany and India show an increasing trend from 1995 to 2009.

The BEET is positive with the USA toward which Italy is a net exporter of emissions. From 1995–2005, BEET with USA increased from 0.2% to 1.3% of Production-based emissions but this trend dropped 0.1% in 2009.

Going more in deep in the analysis, the MRIO model allows us to observe the proportion of emissions embodied in imports, exports and the balance by industry. The database provides a disaggregation of 35 industries and in Figs. 4a, b and c, we plot the graphics displaying Italian CO_2 EEI, EEE and embodied in domestic production with respect to the 15 more relevant industries. As expected, from Figs. 4a, b and c we can see that industry C17 "electricity, gas and water supply" is the major pollutant since it embodied the highest level of CO_2 EEI, EEE and domestic production.

Focusing on Fig. 4a, we can observe the amount of CO_2 EEI, that is to say, the level of emissions flowing in Italy from foreigner industries. As already mentioned, the most relevant amount of emissions associated with imports occurs in industry C17 "electricity, gas and water supply", followed by industry C12 "basic metals and fabricated metal", C9 "chemical and chemical products" and C2 "Mining and quarrying". Notoriously, these industries are those characterised by a very high level of imports in Italy, because of the scarcity of energetic sources. In particular, C17 emissions impact is accounted for 84.9 Mt-CO_2 equivalents in 2005, while export from the same industry in the same year is 26.3 Mt-CO_2 equivalents. It is evident that in 2005 the balance (Fig. 5) is strongly negative.

As showed in Fig. 4b, the highest carbon EEE occur in industries C11 "Other non-metallic minerals", C12 "basic metal and fabricated metals", C9 "chemical and chemical products", C8 "Coke refined petroleum and nuclear fuel". The carbon EEE of industry C11 "Other non-metallic minerals" accounted for 17 Mt-CO_2 equivalents in 2005. From Fig. 4b we can also see that, differently to the other industries that registers a reduction in EEE and EEI, there is a continuous increase of emissions in industry C25 "air transport".

However, a large amount of EEE is related also to primary manufacturing industry, in particular C4 "Textiles and Textile product", C9 "Chemical and chemical products", C8 "Coke, refined petroleum" and C3 "Food, beverages and tobacco". It is important to note that the highest carbon EEE occurs in the same industries (i.e. C17, C11, C12, C8, C9) as EEI. In addition, a quite high share of emissions are attributed to C17 "Electricity, gas and water supply", C8 "Basic metal and fabricated metals" and C9 "Chemical and chemical products" that are acknowledged as energy intensive industries, which are subject to various regulation regarding GHG emissions. Finally, all EEE from energy intensive industries (i.e. C17, C11, C12, C8, C9) amount to an average of 64% while EEI from these industries amount to an average of 66%.

The Fig. 4c gives an indication of Italy emissions embodied in domestic production by industries. The highest level occur again in the industries C17, C11, C8, and C23 and the overall amount represents the 63% of total emissions. The industry C23 "Inland transport" represents the fourth largest source of emissions in Italy with about 16 Mt-CO_2 equivalents on average.

The results on EEE and EEI allow us to determine the BEET by industry for the Italian economy, as showed in Fig. 5 where we reported the performance of the 15 most relevant industries (negative and positive). As we can see, most of them displays a negative value for BEET, meaning that Italian imports of emissions in those industries are higher than exports of emissions. As mentioned, C17 "Electricity, gas and water supply" has the highest negative BEET, which increased by 41% from 1995 to 2009. The other energy intensive industries (i.e.

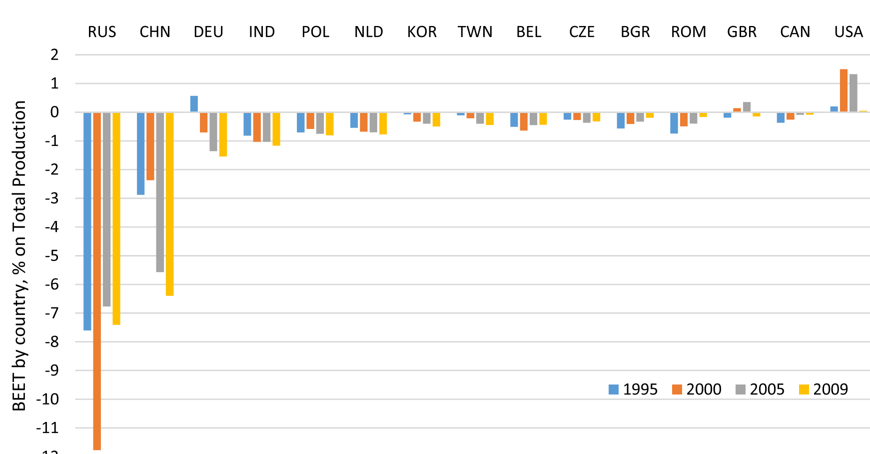

Fig. 3. Italian BEET by Country - Highest performances from 1995 to 2009.

C12 “Basic metals and fabricated metals” and C9 “Chemical and chemical products”) also show a large negative BEET. Among the non-energy intensive industries, C2 “Mining and quarrying”, C23 “Inland transport” and C25 “Air transport” have a negative BEET as well. A positive value for BEET is observed for industries C4 “Textiles and Textile Products”, C11 “Other Non-Metallic Mineral”, C15 “Manufacturing of transport type equipment”, C21 “retail trade” and C20 “Whole sale trade”.

5. Water footprint and water trade in Italy

The depletion and excessive use of fresh water represents one of the environmental problems that the Italian Government is trying to cope with especially because, even though the Italian average annual rainfall is relatively high, the per capita availability of fresh water is one of the lowest among OECD countries [56]. Italian water system indeed, is characterised by high evapotranspiration, rapid outflow, limited storage capacity and a quite heterogeneous distribution of water resources

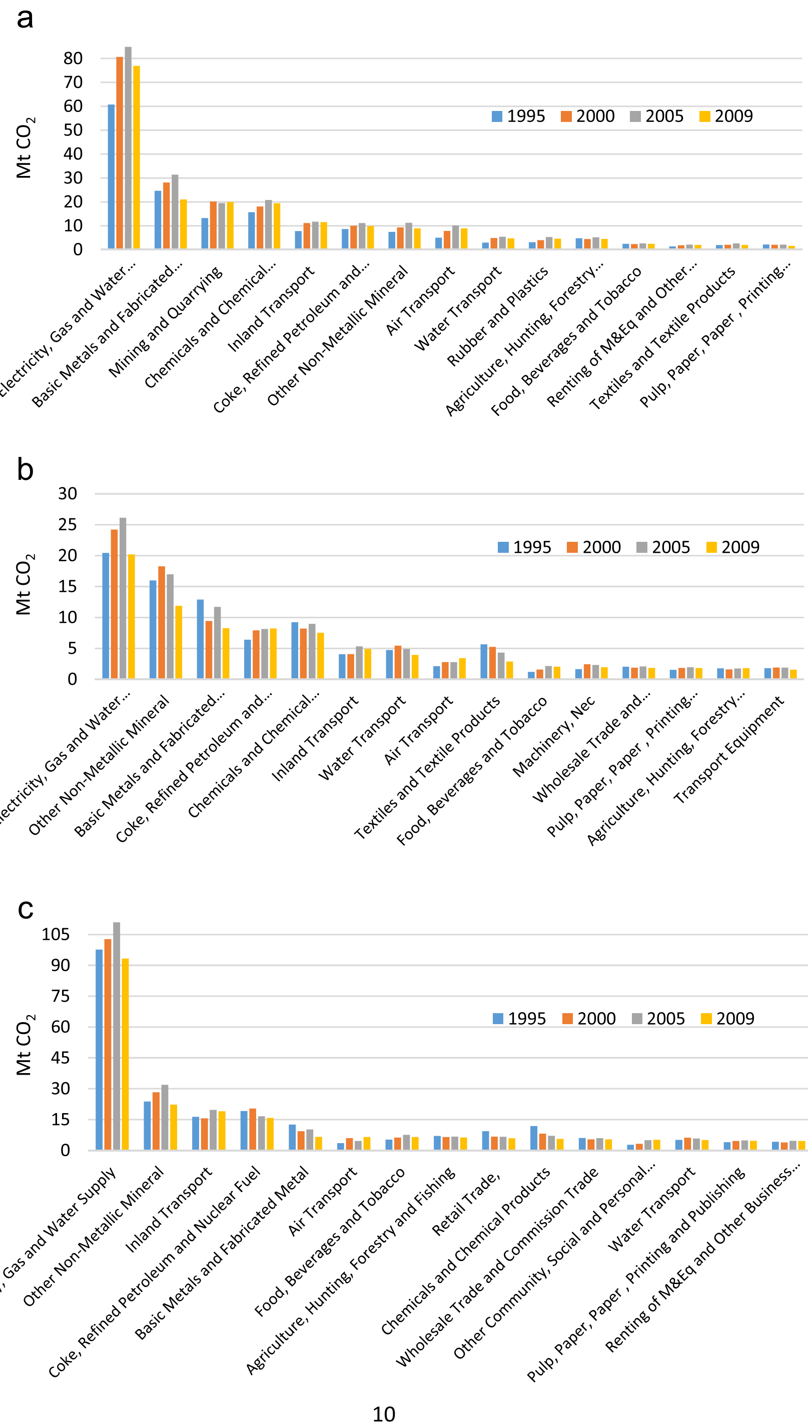

Fig. 4. a: Italian CO_2 EEI by industry. Highest performances – 1995–2009, 4b: Italian CO_2 EEE by industry. Highest performances – 1995–2009, 4c: CO_2 emissions embodied in Italian domestic production by industry. Highest performances – 1995–2009.

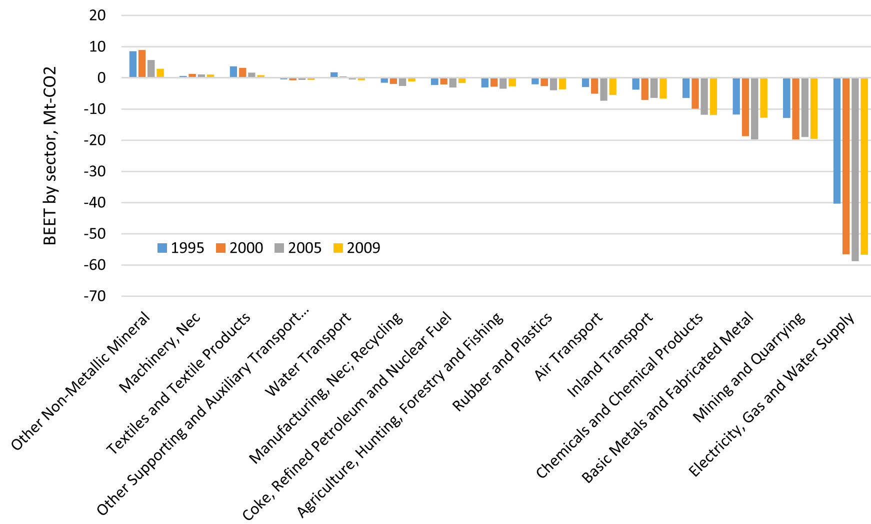

Fig. 5. Italian CO_2 BEET by industry. Highest performances – 1995–2009.

among regions. Moreover, the fresh water consumption per capita is 7.6% higher than the average of the other EU-27 countries from 1996 to 2007 making Italy particularly vulnerable to water scarcity [57].

According to the OECD Environmental Performance Reviews [56], water pollution is a further obstacle to water supply in particular for the northern regions of Italy. However, after 2008–2009 crisis, the improvement in prevention and control, together with the contraction of economic activities, caused a decrease of the pollution pressure on water resources.

In this section, as already done for carbon emissions, we aim to compute the Italian water footprint and water trade in order to determine the international trade incidence on water resources. This is crucial especially to understand if this incidence is relevant compared to the domestic exploitation of water in order to design a proper water management.

5.1. Major Italian water use indicators

The data reported in WIOD environmental database confirms the analysis conducted by OECD on the environmental performances of Italian economy showing an increase in Italian water footprint from 1995 to 2005. The total water footprint of Italy in 2005 was 122.20 km^3 (see Table 2) which represents 1.4% of the total water footprint in the world. From 2005 there has been a reduction in the water footprints of Italy that is accounted as 133.4 km^3 in 2009, corresponding to 1.1% of the total world footprint.

The production based water footprint includes two different components: the first is the domestic water resources demanded to satisfy the domestic production and domestic final consumption of goods and services. The second is the domestic water resources used to produce goods and services destined to be exported to other countries.

The consumption based water footprint represents the total water consumed along the global supply chain to satisfy the domestic final demand.

The production and consumption based water footprint both register a decrease after 2005, but the reduction in consumption is less important than the reduction in production. According to the OECD review, the economic crisis of 2008–2009 generates a contraction in economic activities and thus in production processes. On the contrary, households' water consumption does not follow this trend and raise even in 2009. The combination of households and intermediate consumption determines the overall consumption based water footprint and explains the reason of a minor reduction compared to the production based water footprint.

Table 2
Italian Water embodied in production, consumption and in international trade, 1995–2009.

Water (km^3)	1995	2000	2005	2009
Households Consumption	4.7	4.7	4.8	4.9
Intermediate Consumption	58.8	60.5	59.6	55.1
Water Embodied in Export (WEE)	15.5	16.3	16.7	16.2
Water Embodied in Import (WEI)	58.7	62.6	79.9	73.3
Production Based water footprint	79.0	81.4	81.2	76.2
Consumption Based water footprint	122.2	127.8	144.4	133.4
Balance of Water Embodied in Trade (BWET)	−43.2	−46.4	−63.2	−57.1
WEE as % of Production	19.7%	19.9%	20.6%	21.2%
WEI as % of Production	74.3%	76.9%	98.4%	96.2%
Balance of Water Embodied in Trade (BWET) as % of Production	−54.7%	−56.9%	−77.8%	−74.9%
Italy Water Footprint	122.2	127.8	144.4	133.4

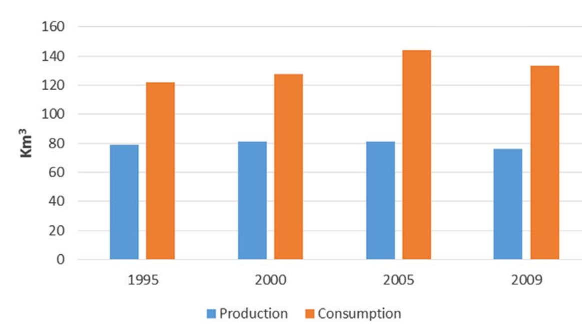

Fig. 6. Italian consumption and production water footprint, 1995–2009.

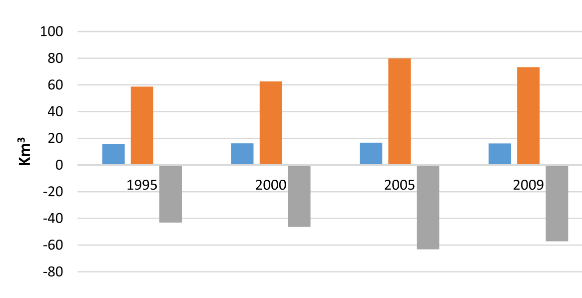

Fig. 7. Italian WEE, WEI and BWET from 1995 to 2009.

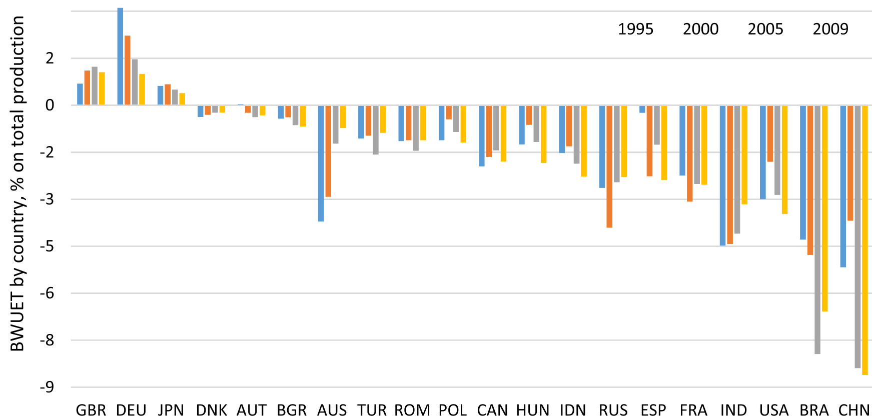

Fig. 8. Italian BWET by country - Major flows from 1995 to 2009.

In Fig. 6, we reported the overall consumption and production water footprint of Italy and, as mentioned, we can notice that during the overall period the consumption based water footprint was significantly higher than the production based water footprint.

From the production-based perspective, water footprint in 2009 accounted to 76.2 km^3, which was about 3.5% lower than water footprint in 1995 of km^3. On the other side, consumption based water footprint increased by about 9.1% from 122.20 km^3 in 1995 to 133.4 km^3 in 2009.

Given the relevance of the water consumption based footprint, we are interested in determining the contribution of imports and exports in the water use.

In particular, Fig. 7 presents the water used to produce the commodities exported abroad (WEE), the water related to commodities imported and consumed in Italy (WEI) and the water trade balance (BWET) which is the difference between water contained in exports and imports. More specifically, the WEE remained stable over the whole period, while the WEI grew by 20% from 58.7 km^3 in 1995 to 73.3 km^3 in 2009. In 1995, WEE accounted for about 19.7% of production based water footprint and in 2009 for about 21.2%. Differently, in 1995 WEI accounted for about 74.3% that grew significantly to 96.2% of production based water footprint in 2009.

The BWET determines the water debit or credit of a country with respect to the other countries. It does not only show the difference between export and import of water, but also the difference between the production based water footprint and consumption based water footprint. The fastest growth in WEI is reflected by a negative BWET trend, meaning that over the period the imported water is higher than the water used to produce goods and services for export. In 2005 the BWET reached its negative peak of −63.2 km^3 and in 2009 it got to −57.2 km^3.

5.2. Water embodied in trade and balance by country and by industry

The MRIO model developed on the WIOD database generates results on water footprint and the other indicators showed in Table 2, with a disaggregation of 40 countries and 35 industries.

In particular, we start describing the disaggregate results of the Italian BWET (showed in Fig. 8) which is the difference between the WEE and the WEI, that is to say, the origins and the destinations of water between Italy and its main trading partners. These results are normalized on production based water footprint accounts.

From Fig. 8 we can notice that most of the WEI comes from China, Brazil, India, Russia and from other developing countries. Focusing on the countries belonging to EU-27, a significant share of water use comes from Spain and France. Germany and Great Britain are the only EU countries toward which Italian WEE is higher than WEI. WEI from Australia have declined since 1995, while WEI from USA increased continuously over the period 1995–2009. WEI from Poland, Romania and Turkey were very similar over the whole period. The water embodied in trade with the other countries indicates a prevalence of WEE, thus a positive balance. WEE to Germany decline over the period, reaching to the lowest account 1 km^3 in 2009.

We can also analyse the amount of water associated to production for domestic consumption, for export and the water associated to imported goods by industry, taking advantage of the MRIO model that considers 35 industries.

Figs. 9a, b and c display the WEE, the WEI and the water use embodied in Italian domestic production by industry.[3] In general, we can observe from all figures that industry C1 “Agriculture, hunting, forestry and fishing” is the highest water embedded industry for Italian economy.

More in detail, from Fig. 9a, we observe that the highest level of WEI occurs in industries C1 “Agriculture, hunting, forestry and fishing” and C17 “Electricity, gas and water supply” as they are considered the water intensive industries. Fig. 9b shows the amount of WEE by industry and, apart from C1 “Agriculture, hunting, forestry and fishing”, the other industries with a high level of WEE are C17 “Electricity, gas and water supply”, C9 “chemical and chemical products” and C4 “Textiles and textile products”. In these industries WEE has a positive trend until 2005, then it declines, as already observe for other indicators. The Fig. 9c, that complete the overviewing of water uses, emphasises the industries having the highest water footprint in domestic production. As expected, standing out industries are C1 “Agriculture, hunting, forestry and fishing” and C17 “electricity, gas and water supply”. The overall water use from these industries is around 94% of the total use of water for domestic production.

Fig. 10 displays the results of the WBET by industry, thus the difference between the WEE and the WEEI. We can see that the highest water intensive industries are C1 “Agriculture, hunting, forestry and fishing” and C17 “electricity, gas and water supply”. The first one is the most relevant industry in terms of negative BWET, meaning that the water embodied in imports is higher than the water embodied in exports from this industry. This result is generally replicated for all the other industries discussed above that has a level of WEI higher than WEE. Only few industries register a positive BWET and they are C4 “Textiles and textile products” and C11 “other non-metallic mineral”. The first one is notoriously the industry with the highest level of exports as it represents the best productions in Italy, while the second one is positive because of a very small level of imports and water intensity.

[3] Industries showing no flows of water are not displayed in figures.

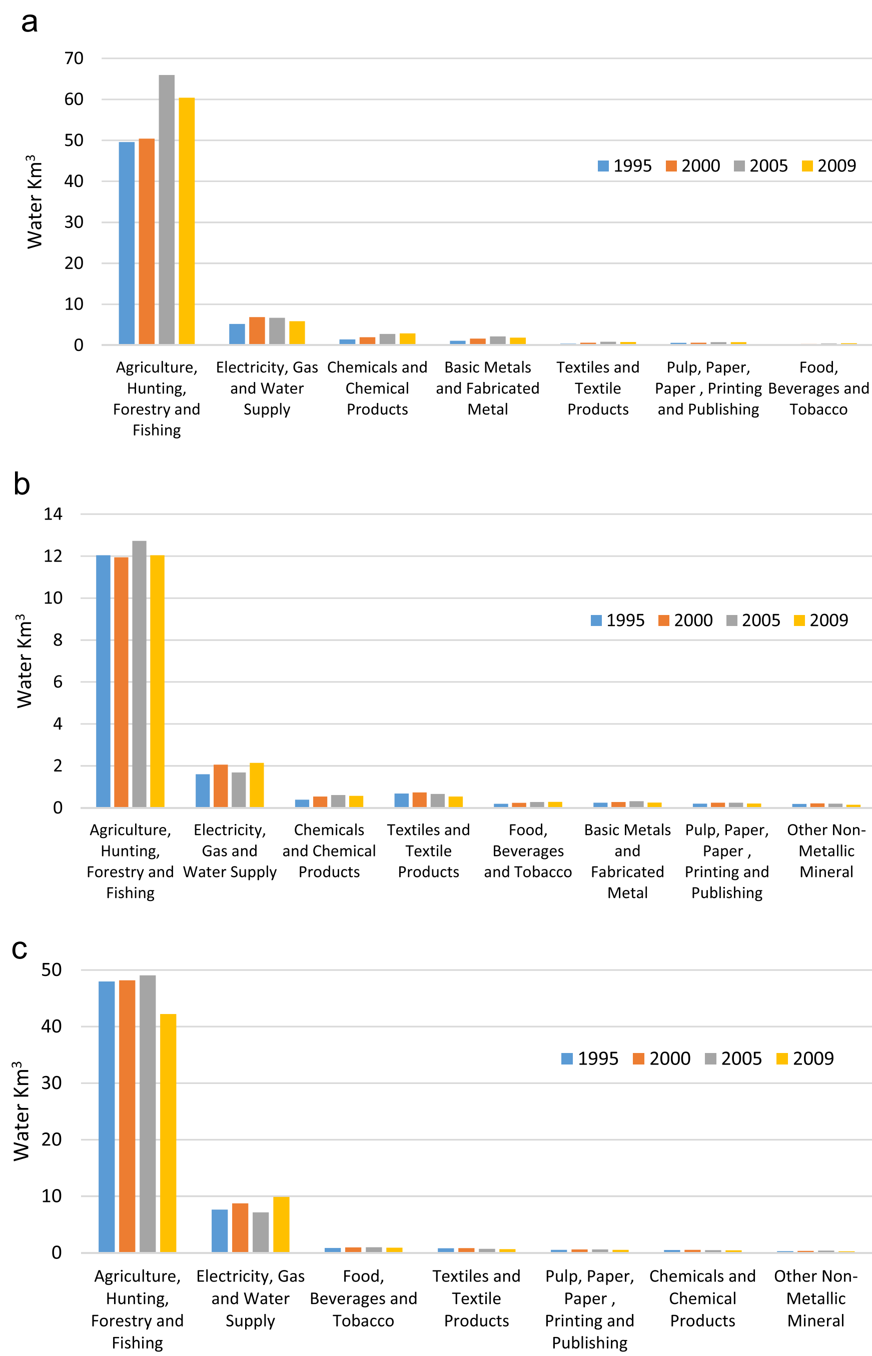

Fig. 9. a: Italian WEI by industry. Major flows from 1995 to 2009, b: Italian WEE by industry. Major flows from 1995 to 2009, c: Water use embodied in Italian domestic production by industry. Major flows from 1995 to 2009.

6. Conclusion

In the last decade, Italian Government paid a great attention to environmental issues and in particular to the control of CO_2 emissions level and to the sustainable use of water. The promotion of green economy demonstrated a high effort in dealing with environmental issue however, the important decrease in carbon emissions (around −23% with respect to 1990) and water footprint significantly depends on the economic crises of 2008–2009 [56]. This demonstrates the urgency for the policy maker to promptly detect the origins of emissions and then introduce the most adequate policy measure.

In last decades, the use of carbon footprint and water footprint indicators became quite popular in determining the pressure of human activity on environment despite the lack of scientifically accepted guidelines for their calculation. Moreover, these indicators should also take care of the international trade, shifting the determination of the environmental pressure to a more consumer and producer base. In the literature indeed, the idea that the flow of pollution through international trade flows has the ability to undermine environmental policies is supported by many studies.

In this respect, we demonstrated that it is possible to evaluate the environmental pressures of production and consumption distinguishing between exported, imported and domestic pressures using a Multi-Regional Input-Output model. In particular, we examined the amount of CO_2 emissions (carbon footprint) and the water use (water footprint) embodied in international trade of Italy from a consumer and producer perspective to assess the incidence of trade on domestic environmental exploitation.

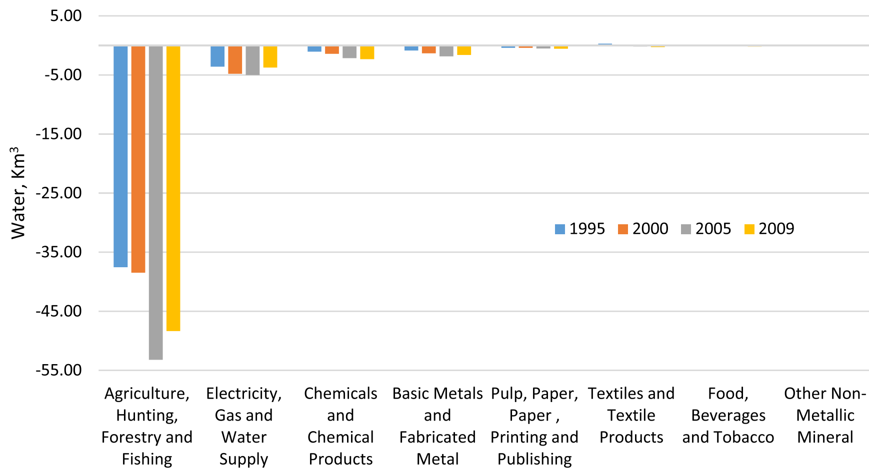

Fig. 10. Italian BWET by industry. Major flows from 1995 to 2009.

The consumption-based approach can be used as an alternative way to allocate responsibility between the emitters and the final consumers more fairly. Indeed, the analysis carried out demonstrated that a huge amount of CO_2 emissions for the Italian economy is related to the international trade. In particular, CO_2 emissions associated with Italian imports are greater than CO_2 emissions associated with Italian exports that remained stable over the observed period from 1995 to 2009. This makes negative the Italian balance of emissions embodied in trade, meaning that Italy is a CO_2 consumer rather than a CO_2 producer. Furthermore, the disaggregated analysis demonstrated that most of CO_2 emissions associated with Italian trade originates in industries that are more energy intensive and typically more polluting.

Similarly, as regard to the water footprint, the analysis carried out demonstrated that in Italy the water used to produce goods and services exported abroad remained stable over the whole study period, while water embodied in imports grew by 20% in 2009 with respect to 1995. A negative balance of water embodied in trade reflects the fastest growth in water use related to imports, meaning that the water incorporated in imports of goods and services is higher than the water incorporated in exports. These results validate a notorious peculiarity of the Italian water system that is characterised by high evapotranspiration, rapid outflow, limited storage capacity and a quite heterogeneous distribution of water resources among regions [57]. The industries that absorb the highest quantity of water are "Agriculture, hunting, forestry and fishing" and "Electricity, gas and water supply". Since the imports of these industries are greater than exports, we observe for the Italian economy a negative sign for the water trade balance.

These outcomes provide interesting information to the policy maker that is engaged in promoting environmental policy measure to cope with the European Union environmental policy targets. As showed by the analysis, the consumption represents the most relevant cause of water exploitation and CO_2 emissions, more than industries do. This is remarkable if we consider that Italian policy maker attention mostly focuses on production more than consumption processes. In this perspective, the recent initiatives taken by the Government to promote the green economy and the transition to renewable energy sources should be accompanied by other initiatives aimed to the regulation of the consumption of particularly pollutant goods and services. This is a not easy task especially because in the past some measures aimed to reduce the carbon emissions led to an increase of environmental taxation with very small results.

In terms of global climate change, controlling the unbalance between imported and exported resources and emissions should promote the responsibility of each country in reducing the environmental pressure of human activities. Italy in particular, is a net importer of carbon emissions and water sources. As regard to the first position, it means that the main responsible for Italian level of emissions is the consumption, more than production. As regard to the position of water importer, this condition exposes Italy to water stress and to an increase in the future competition for water resources.

Appendix A

See Table A1 and A2.

Table A1
Countries included in World Input Output Tables (WIOT).

NO	Code	Country	NO	Code	Country
1	AUS	Australia	22	ITA	Italy
2	AUT	Austria	23	JPN	Japan
3	BEL	Belgium	24	KOR	S-Korea
4	BGR	Bulgaria	25	LTU	Lithuania
5	BRA	Brazil	26	LUX	Luxembourg
6	CAN	Canada	27	LVA	Latvia
7	CHN	China	28	MEX	Mexico
8	CYP	Cyrus	29	MLT	Malta
9	CZE	Czech Republic	30	NLD	Netherland
10	DEU	Germany	31	POL	Poland
11	DNK	Denmark	32	PRT	Portugal
12	ESP	Spain	33	ROM	Romania
13	EST	Estonia	34	RUS	Russia
14	FIN	Finland	35	SVK	Slovakia
15	FRA	France	36	SVN	Slovenia
16	GBR	United Kingdom	37	SWE	Sweden
17	GRC	Greece	38	TUR	Turkey
18	HUN	Hungary	39	TWN	Taiwan
19	IDN	Indonesia	40	USA	U-S of America
20	IND	India	41	RoW	Rest of the world
21	IRL	Ireland			

Table A2
WIOD database industries in each country.

ID	Industries	ID	Industries
C1	Agriculture, Hunting, Forestry and Fishing	C19	Sale, Maintenance and Repair of Motor Vehicles & Motorcycles; Retail Sale of Fuel
C2	Mining and Quarrying	C20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
C3	Food, Beverages and Tobacco	C21	Retail Trade, Except of Motor Vehicles & Motorcycles; Repair of Household Goods
C4	Textiles and Textile Products	C22	Hotels and Restaurants
C5	Leather, Leather and Footwear	C23	Inland Transport
C6	Wood and Products of Wood and Cork	C24	Water Transport
C7	Pulp, Paper , Printing and Publishing	C25	Air Transport
C8	Coke, Refined Petroleum and Nuclear Fuel	C26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
C9	Chemicals and Chemical Products	C27	Post and Telecommunications
C10	Rubber and Plastics	C28	Financial Intermediation
C11	Other Non-Metallic Mineral	C29	Real Estate Activities
C12	Basic Metals and Fabricated Metal	C30	Renting of M & Eq and Other Business Activities
C13	Machinery, Nec	C31	Public Admin and Defence; Compulsory Social Security
C14	Electrical and Optical Equipment	C32	Education
C15	Transport Equipment	C33	Health and Social Work
C16	Manufacturing, Nec; Recycling	C34	Other Community, Social and Personal Services
C17	Electricity, Gas and Water Supply	C35	Private Households with Employed Persons
C18	Construction		

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