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Evaluation of the energy consumption and greenhouse gas emission related to Italian food consumption with an hybrid LCA-IO method

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Abstract

In the recent years the evaluation of environmental sustainability of lifestyles and consumption practices is getting a central role in European researches. Several analytical tools and methodologies are proposed in order to quantify the environmental burden of production and consumption. Environmental impact assessment methods are mainly divided in bottom-up (e.g. the Life Cycle Assessment - LCA) and top-down (e.g. the Input-Output Analysis - IOA), the first is focused on production processes and the second on the macroeconomic dimension of a community. Thus both of them are unsuitable to investigate at the level of practices and lifestyles.
We discuss the advantage of an hybrid IOA-LCA method, which is developed to consider both positive aspects of bottom-up and top-down methodologies, in the evaluation of household consumption. This method has been applied just to the food sector as a test of the whole methodology.

1. Introduction

In this article we highlight the theoretical background of the ongoing research program GERME (Green Economy Research on the Mediterranean Environment), which aims at studying the relationship between socio-economic dynamics and their environmental effects in Italy and other Mediterranean countries. The idea that stands at the base of this analytical protocol is that a thermodynamic assessment of different types of household provides useful information about options for change in lifestyle.
Food consumption is considered one of the most important aspects in the environmental burden of households. Indeed, according to a recent literature review (Hertwich, 2011) on the

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environmental impacts of consumption, shelter accounts for 35-53% of the total energy use; mobility, including fuel use, vehicle purchase and public transportation, accounts for 15-31%; food accounts for 11-19%; recreation accounts for 4-10%, clothing 3-5%, and health 1-5%. It has to be noticed that in this review the energy use in some foods, consumed in restaurants, hotels, as part of package tours, or in educational and health care institutions, is not allocated to the food category but listed under other, recreation, transportation or government consumption.
Taking into account the GHG emission form household consumption, a comprehensive research across Europe 25 has been conducted in 2006 (Tukker et al., 2006). In this study the GHG emission accounts for 31% for food, beverage, tobacco and narcotics; 2% for clothing and footwear; 24% for housing, furniture, equipment and utility use; 2% for health; 19% for transport; 2% for communication; 6% for education; 9% for restaurants and hotels; 5% other goods and services.
In this paper a preliminary application of an hybrid environmental assessment method has been applied just to the food sector as a test of the whole methodology.

2. Methods

2.1 Needing of an hybrid accounting method

Several analytical tools and methodologies are proposed in order to quantify the environmental burden of production and consumption. Environmental impact assessment methods are mainly divided in bottom-up (e.g. the Life Cycle Assessment - LCA) and top-down (e.g. the Input-Output Analysis - IOA), the first is focused on production processes and the second on the macroeconomic dimension of a community.
In order to assess GHG emissions and energy consumption al the product level, most company use 'bottom-up' approaches, summing estimates of emissions associated with specific goods and resources used during the productive process, thorough a process-based LCA to estimate the impacts across an inventory of activities and purchases. Nevertheless, a number of authors (Wilting, 1996; Kok et al., 2003, Huppes et al., 2008) highlight that this approach suffers from 'truncation error', and when applied in household consumption, it leads to serious underestimation of the total impacts. The truncation arises from the inevitable omission of steps and processes in order to make the task manageable. LCA defines the system as a finite number of steps, which, in most cases, provide an adequate estimation (Baumann and Tillman, 2004); however, whit this method it will never be possible to consider a "total economy scenario".
On the other hand, there are 'top down' analyses, which use Input–Output Analysis (IOA) and are able to locate emissions to different sectors considering the total economy of the Country. Thus this approach has the benefit of not underestimating global figures, but the calculations are only made for economic sectors and not for certain products. This means that the IOA gives cruder estimates than an LCA does, but on the other hand the accounting is more comprehensive. Furthermore, IOA indicates an emission factor per Euro consumed in a certain sector. This is considered a very useful task, even if it could lead to the 'aggregation error' as the input–output coefficients for each industry are averages derived from the comprehensive natural summation of all the related, but not identical production processes. However, as the

individual processes are not individually discernible, it lacks the potential for specificity of the bottom-up approach (e.g. Wiedmann, 2009)
Recently a revised environmentally extended input output databases (E3IOT model) has been proposed by an European panel of experts (Huppes et al. 2008). This model aim to evaluate emission form the whole supply chain of products in order to assess environmental impacts of final consumption. This method is potentially very useful because avoids having to extrapolate the environmental impacts of very specific products to whole product groupings (which bears a high risk of not being representative), but requires required highly disaggregated input-output tables with environmental information are not readily available for the EU-25 and considerable efforts are required to construct them (Huppes et al. 2008).
Therefore, a number of hybrid models that combine the LCA and IOA have been developed to describe the consumption systems from a thermodynamic point of view, in an attempt to benefit both from the completeness of EIOA and from LCA's potential for specificity (Hertwich, 2011).
Within the GERME research project a hybrid LCA-IOA method was conducted on the basis of the works of Wiltings (1996), to calculate the energy requirement of food consumption in Italian households.

2.2 Methodology

The hybrid method is mainly based on the life cycle of products from specific product categories. In each stage of the product life cycle, a specific quantity of energy is consumed and emission are produced. However, as some stages of the life cycle cannot be accounted in physical units, all parts of the life cycle are priced. The starting point of the allocation of economic value of a product in its life cycle is the consumer price. This price is the sum of costs of each processes in the life cycle of the studied product (manufacturer price), commercial margins and taxes. For the present research the considered consumer prices and taxes were taken are from the Italian Ministry of Economic Development (Osservatorio prezzi e tariffe, 2010) and commercial margins per commercial sector were calculated from the National Input-Output matrix.
Once the manufacturer price is known, it will be use to complete the financial balance of the product completing the following equation:

$$\textit{Manufacturer price} = \textit{(I) basic goods} + \textit{(II) packing} + \textit{(III) direct energy} + \textit{(IV) added value} + \textit{(V) depreciation} + \textit{(VI) residual goods}$$

where: (I) basic goods is the sum of the prices of each good used in the production of the final product; (II) packaging in the sum of the prices of each packaging material used in the preparation of the product for the commercial phase; (III) direct energy is the cost of the energetic material consumed during the production as a percentage of the manufacturer cost related to the production sector; (IV) added value for each sector is obtained by the National Input-Output matrix and it is expressed as the net value from labour; (V) depreciation per sector is obtained by the National Institute of Statistic (ISTAT – *Database: Conti economici nazionali*); (VI) residual goods as the difference of each other cost from manufacturer price.

Subsequently, to each component of final cost of the product it is possible to associate an environmental burden in terms of MJ/€ and $kgCO_2$-eq./€.
Therefore, the impact from each phase of the life cycle of product is accounted as follow:

- *basic goods* and *packaging* are accounted via bibliographic LCA studies and international databases, in terms of energy and emission per unit of material;
- *residual goods* are accounted multiplying the cost of residual good for the energy intensity (or the emission intensity) of residual goods from the relative sector, using the National Input-Output matrix following the formula described by Wilting (1996):

  $$e_J^r = \frac{\sum_i e_i X_{iJ}}{\sum_i X_{iJ}}$$

  where: e_j^r is the energy intensity of residual goods of sector J; e_i is energy intensity of sector i; X_{iJ} is the intermediate delivery from sector i to sector J

- *capital goods* are accounted multiplying the cost of depreciation for the energy intensity (or the emission intensity) of a dummy sector called depreciation, which has been inserted for such purpose in the Input-Output matrix;
- *direct energy use* is accounted as the MJ consumed by the cost of direct energy in the product at the average national energy cost;
- *transport* is accounted multiplying the km/t made by each product for emission factors specific of the transport mean;
- *trade* is accounted multiplying the economic contribution of the commercial margins for the energy or emission intensity of the commercial sector;
- *waste* is accounted multiplying the quantity of wasting material (from production, storage and transportation) for the emissions of energy consumption of the relative management strategy obtained by international LCA databases.

2.3 *Main advantages of the method*

Compared to other assessment tools, the hybrid method solve problems in the accounting of capital goods and foreign trade. As well known, the Leontief model, mainly used in environmental applications, considers only intersectoral transaction of the actual productive activities in a given year. Transactions relating to the safeguarding and enhancement of the equipment fixed (or stocks of raw materials and semifinished) are being combined into a single item of final demand called investment. In this way, these are not endogenous to the production, but are elements to be determined independently. This effect is a problem as the investments needed in part to create new production capacity but also to replace worn out the share of fixed capital in the process of annual production. Thus the question is: how to consider the role of investments in an analytical framework, such as the evaluation of the carbon footprint of consumption of the population? A number of methods have been proposed: there are studies which simply ignore the issue and other which propose a complete inclusion of investments.

Nevertheless the most appropriate method should involve the segregation from the vector of final demand an amount equal to depreciation and its internalization in the matrix of cross-sectoral exchanges. This kind of solution is thus adopted by the hybrid model which introduces a fictitious sector called depreciation. This sector is accounted for the redistribution of externalities embedded in the use of annual capital equipment based on the share of depreciation specific to each sector of the economy.
In the issue of foreign trade, the hybrid model has the advantage of distinguishing clearly between competitive and non-competitive imports, depending on whether it's goods and services that are produced or not at the Country level. Imports of the first type are included in the matrix of intermediate exchanges, under the assumption that the production structure of the country from which matter is similar to that of the country examined. These assumptions are not unreasonable also in the Italian context, which imports mainly from other Western countries.

2.3 Construction of the database for food products

A specific investigation about food products was conducted to obtain data on the various aspects involved for assessing environmental impacts, especially in terms of energy consumption and emissions.
The build-up of the database for the hybrid model calls for investigating each item taking into account:

- environmental aspects resulting from the application of methodologies encompassing the entire product life cycle,
- average percent composition of types of packaging used,
- distances covered by products to reach the place of consumption,
- waste management.

Assumptions made for each point must be explained, due to the lack of data in Italian research.
All potential data on emissions from companies and research institutes were considered, but it would be impossible to set an average panel of data in this way.
LCA studies carried out in Italy, such as studies on wine (Ardente et al., 2009), on rice (Blengini and Busto, 2009) and fruits (Cerutti et al., 2010) have been taken as case study, considering the modest scientific research hitherto available in Italy on food product environmental evaluation by this methodology.
Environmental Product Declarations (EPD) were also considered, as derived from LCA studies on products of large producers such as Pasta Barilla, also a national market leader. Each EPD reported environmental indicators calculated for comparison between products of the same category. Other EPDs employed are about cookies, crackers, milk, wine, oil, bier and water.
The question about whether or not an LCA study on a specific case could be sufficiently representative of other realities is a matter for discussion, linked to the possibility of using an Italian LCA database which would contain average data, although not yet existing (Vesce et al., 2012).
To evaluate trading of food products a prior analysis of the retail sector in Italy was needed. Food products are distributed mainly by hypermarkets, supermarkets and superstores, cash-and-

carry and hard discount stores. The area is highly diversified, due to the classification of "fresh products" or "medium" or "long" best before date.
Lack of data on average product distance to market, even from professional associations, has been a significant factor. Accordingly, data was obtained through:

- selection of market leader for each product category,
- selection of towns, according to geographic distribution,
- calculation of distance from market leader to towns and average distance covered in Italy.

Moreover, aggregate data on distance covered by food products according to the Italian Ministry of Infrastructures and Transports, Statistics Office and National Statistics System (2009-2010), illustrate energy consumption versus distance, related to the kind of transport employed for delivery.
As regards average packaging research, the approach included:

- research on the local situation (consultation with CONAI, national packaging consortium and consortia representing major packaging materials operators) and Europe (European shopping basket),
- analysis of packaging data extrapolated from Environmental Product Declaration,
- assessment of data received from professional associations of large distribution operators,
- direct evaluations in Hypermarkets.

The sources investigated did not provide sufficient information for establishing which packaging was used and in which percentage for each packing material (such as plastic, cardboard, glass), but the waste recyclers only provided aggregate data.
Data collated was mainly the result of visits to hypermarkets owned by major local retailers (Coop Italia, Conad, Auchan) (AC Nielsen, January 2011), for the purpose of assessing the material mix used for the different products.
The main share of food product waste considered comes from packaging, with a minor contribution by organic waste. Data from the Urban Waste Report 2012 (ISPRA, 2012) illustrate the situation of waste recycling or disposal of different materials in Italy. This information was used to delineate an equivalent scenario for each material, considering the same percentage for recycling and disposal respectively.
From the study and investigation carried out it was possible to assess the scale of food product environmental impact, including both direct emission and transport, packaging and waste management, as the way in which these aspects are governed contributes to global impact and affects resulting consequences.

2.4 Application of the method to the Italian food consumption

The described method has been applied in the Italian context, just in the food sector as a test of the whole methodology. Family food consumption expenditure has been obtained by the ISTAT database as the average and in relation to the number of the components.

3. Results and discussion

Energy consumption for food in the Italian family was assessed as 4511 MJ per average family, with a main contribution of basic goods (1665 MJ), trade (831 MJ) and residual goods (767 MJ). The complete distribution of energy requirements of the food expenditure is summarized in figure 1. GHG emissions for food in the Italian family was assessed as 445 kg CO_2-eq per average family, with a main contribution of basic goods (264 kg CO_2-eq), packaging (61 kg CO_2-eq) and trade (51 kg CO_2-eq). The complete distribution of GHG emissions of the food expenditure is summarized in figure 2.

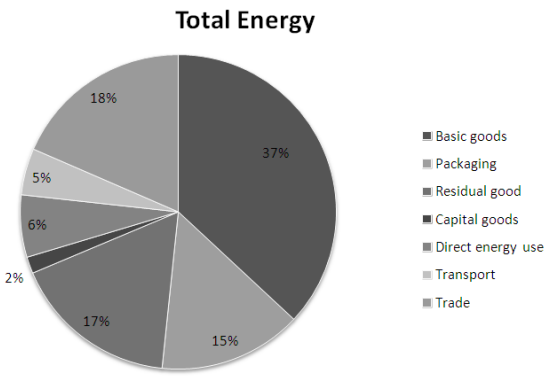

Figure 1. Distribution of energy consumption among the different life cycle stages of food products

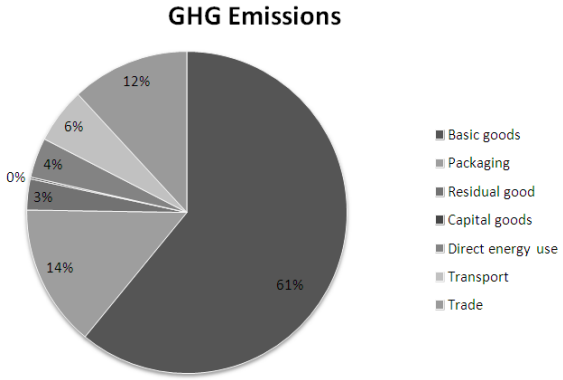

Figure 2. Distribution GHG emissions among the different life cycle stages of food products

The family components breakdown show the similar trend for both energy consumption and GHG emissions: families with 5 or more component have the highest impact considered in the whole, but they have the lowest impact per component (figure 3 and 4).

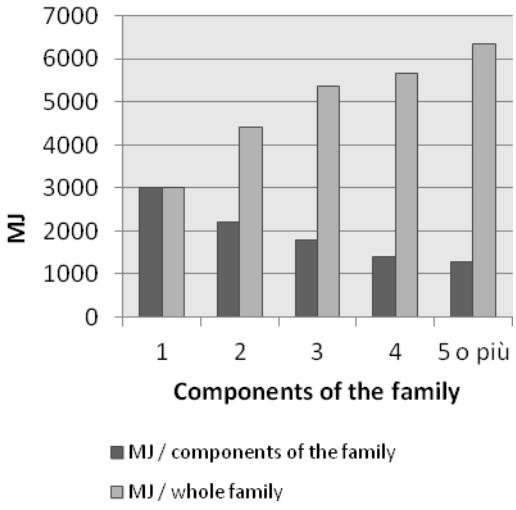

Figure 3. Household breakdown of energy consumption

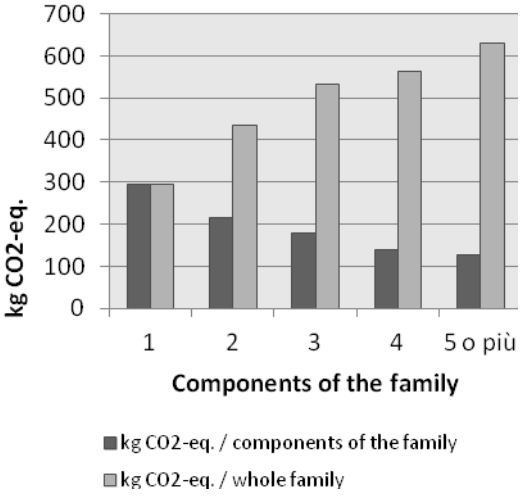

Figure 4. Household breakdown of GHG emissions

As expected, single-person families have the highest environmental impact because per person, beacuse they tend to consume more per person compared to those living in larger households and sharing resources, resulting in higher domestic consumption. Single-person households are an important consumer segment but the still running economic crisis has evidenced the intrinsic weakness of single persons households facing economic troubles, pressing many of them to literally "go parents home" or radically change their life downwarding their expectations. Therefore social aspects of the consumption patterns adopted by each household have to be considered and discussed.

4. Conclusion

The household metabolism model entails relevant aspects at the methodological level. It has some innovative aspects presenting a useful hybrid LCA-IOA model including not only the indirect energy embodied in goods at the final consumption stage, but also the energetic contribution of capital goods and foreigner trade.
The proposed method allows the achievement of a detailed analysis within a systemic framework, which is required for investigations in complex systems such as the food sector.
Results from the application of the model to the Italian food consumption context show the suitability of such tool for the evaluation of energy requirement for Italian families, but precise descriptions about production of goods and management of services in other sectors are necessary to achieve complete results about the environmental impact of the whole family expenditure. Therefore, further works will focus on the implementation of the environmental impacts in households for other consumption categories, such as transportation and direct energy use, to arrive at the evaluation of the whole environmental burden of the average Italian family.

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