On the use of LCA indicators for the environmental assessment of food systems: the case study of the Mediterranean Diet

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Abstract

The broad recognition of Life Cycle Assessment (LCA) as a science-based methodology for environmental assessment of products has paved the way toward extending it into a framework for sustainability analysis. This work analyses the applicability of the method to environmental sustainability questions posed from different points of view. The case study of the Mediterranean Diet is considered, as it allows formulation of options under two different perspectives on food system sustainability. The approach is inspired by conceptual modelling and focuses on analysis of the modelling paradigms of LCA. Our findings confirm hypotheses expressed in the literature that not all perspectives on sustainable food systems could be captured by such modelling paradigms.

1. Introduction

Nowadays environmental, social and health objectives bring into the policy agendas the need to look for novel pathways for the food system, which depart from economy of scale objectives. Within this multi-objective policy landscape, sustainability assessments are expected to play a benchmark role for food system reforms (iPES FOOD, 2015). The tools based on LCA are becoming increasingly popular in informing policy makers about sustainability performance of food systems. LCA methods have gained particular relevance in the European policy arenas especially after the publication of the Product and Organisational Environmental Footprint methods (EC, 2013), whose aim is to "develop an approach that could be used in existing and new EU policies" (Galatola, 2014). The heart of LCA is the system-based thinking, called "Life Cycle Thinking" (LCT) determined by product life cycle perspective, when assessing products' performances. Today it is considered a sound base in extending LCA to encompass other dimensions of sustainability, to broaden the object of analysis on meso and macro-scales and to deepen modelled relations and mechanisms (Guinée et al., 2011).

Even if LCA is considered a mature instrument based on science and mathematical rigour, there are few works in the literature, which analyse its conceptual structure and properties of the underlying modelling paradigms and the corresponding assumptions and conditions under which it can be correctly applied. The focus is mainly on procedural elements, which explain how to built life cycles and how to compute them with the help of software instruments. The main objective of the present study is to link the "world-views" in the base of LC-thinking to the way footprint numbers are computed by means of LCA. The aim is to further disclosure the conceptual model of LCA, which determines the way economic systems are represented for subsequent analysis.

The Mediterranean Diet has been selected as a case study for the analysis of LCA since it allows for identification of options under two different perspectives. The modelling paradigms of LCA are examined in relation to system characteristics considered relevant by each point of view. The study builds upon epistemological analysis of LCA (Heijung, 1997), mathematical modelling employed in computation of LC inventories (Heijungs and Suh, 2002; Suh and Huppes, 2005) and analyses of the way LCA is being used (Freidberg, 2014; Garnett, 2014; Heiskanen, 2000). Our findings confirm hypothesis expressed in (Garnett, 2014) that not all perspectives on sustainable food systems can be captured within the modelling paradigms of LCA.

2. Approach

The approach followed within this study starts from the assumption that there can be different points of view about food system sustainability (Galli et al., 2016). Such differences could arise from considering as relevant not completely overlapping sets of food system characteristics.

We adopt the three perspectives on framing food systems sustainability identified in (Garnett, 2014): efficiency, demand-restrained and system transformation perspectives. It is important to recognise that there could be more perspectives than those three, but for the purpose of the present study, they provide sufficient base for analysis. All three perspectives bear ideological components even though options prioritised by each of them are based on scientific findings. Efficiency perspective prioritises technological innovation, demand-restrained – nutrition science evidence linking nutrition and health, and system transformation - knowledge based systems and ecological management of farms (Wezel et al., 2009). While LCA seems to be a useful tool in assessing environmental performances of food systems from efficiency and demand-restraint points of view, its adequacy in capturing system transformation perspective is questionable (Garnett, 2014).

The modelling paradigms on the base of LCA are analysed with the help of techniques from the discipline of conceptual modelling. Conceptual modelling deal with concepts and relations between them with the aim to facilitate communication and understanding among actors involved in the model development and use processes (Wilmont et al., 2013). Its focus is on characteristics of a problem domain considered relevant and captured in models. Conceptual models facilitate linking mental models and perspectives to formal modelling tools implemented within software systems. Figure 1 illustrates how food system perspectives are linked with LCA modelling instruments. In the subsequent sections a more detailed analysis of the LCA conceptual model will be presented as well as some problems arising with the system-transformation perspective will be discussed through a case study of the Mediterranean Diet.

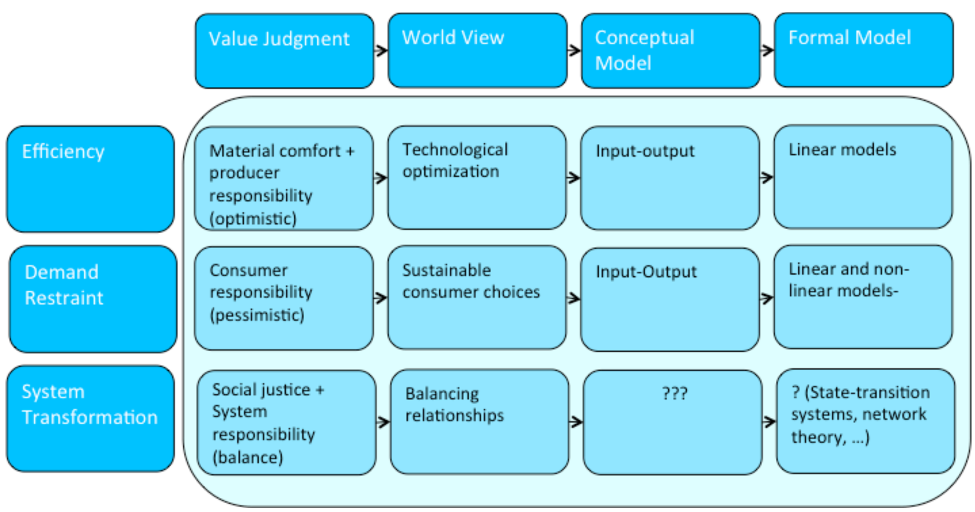

Figure 1 Linking perspectives to models

2.1 Conceptual modelling

"Conceptual modelling" is a term and a discipline in its own, which reflects needs, shared by a number of separate disciplines, for understanding and communication in the processes of model development and use (see Brodie, 2009; Geofrion, 1987). Understanding is conceived on the base of a multi-level interpretation system, which is focusing on conceptual level and which links aligned mental models (or worldviews) of modellers and users of a model with the formal constructs into which the model is eventually expressed. Formal representations of the models could be on several levels, i.e. expressions recorded in a mathematical notation or in computer code (see Fig. 2).

As a discipline conceptual modelling is strongly influenced by linguistics, cognitive science, philosophy and formal logic. To the authors' knowledge, the linguistic notion of "worldview" (Underhill, 2009) is universally assumed. Some scholars, influenced by constructive logic theories[1], accept also the Saphit-Whorf hypothesis that thought is language-dependent, which has profound consequences on the type of tools designed in order to help communication and understanding (see Partrige et al., 2013 for a discussion, and see Wilmont et al., 2013 and Chekland, 1995 for examples). The paper follows this latter latter current.

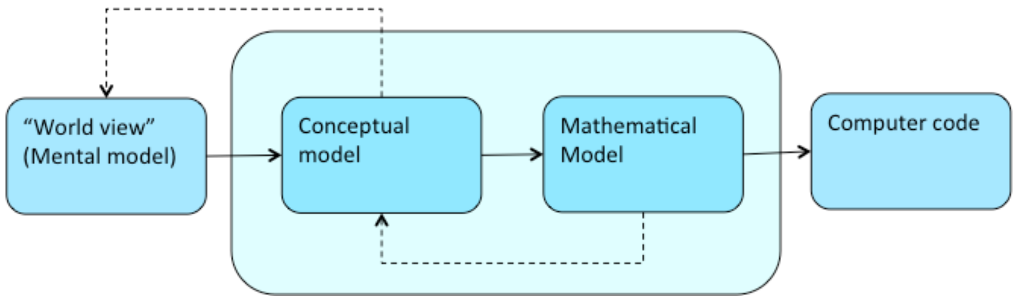

Figure 2 Relations between world-views, conceptual models, mathematical models and software.

Recalling the seminal definition of M. Minski, in the field of Artificial Intelligence (Minski, 1968): "An object A is a model of an object B for a modeller C if the modeller C can use A in order to answer questions that interest him about B", it follows that a model is not an absolute entity, it is subjective and reductionist in a sense that it expresses the "world-view" of the modeller on the problem domain of which B is an entity. It is the modeller, which decides how to represent entities to be modelled, and which of their characteristics are relevant for his purposes. In this definition, the modeller is a collective role, comprising both model developers and users. In an ideal situation, model developers and users share a common "worldview" on a problem domain, which assures that, on one hand relevant for the user characteristics of B are being captured in A and on the other, that the model user understands the model A and applies it correctly for the purpose it serves. In practice, such ideal situations are rather rare, especially when modelling instruments are being developed and used by many people. The aim of conceptual modelling is to provide tools for learning and reflection, which help model developers and users to align and share "worldviews" about a domain. Such tools are used in a continuous and interactive process, in which mental models are "written" down, shared, constructed back in the mind, by interpreting descriptions, and so on until a shared view is achieved.

A conceptual model of a problem domain can be regarded as a declared or written "worldview". It can be thought as a language, in terms of which specific models of domain entities can be expressed. In this sense, concepts are analogous of word classes (or parts of speech), while relations between concepts correspond to grammatical rules. Two cognitive processes are central to the model development and use: abstraction and relational reasoning (Wilmont et al., 2013). These processes help in constructing or understanding concepts and relations between them by relating them to vast body of concrete knowledge and/or experiences about the problem domain. They are used in continues and interactive process of meaning formation and learning resulting in "writing" and "reading" of representations and in constructing, aligning and adjusting "mental models" of a domain (Johnson-Laird, 1983).

In the present paper, natural language in combination with mathematical notations will be used, in order to describe the conceptual model of LCA. It is important to note, that LCA guidelines and case studies often make use of a convenient graphical notation, aiding the process for

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[1] As opposite to classical logic, constructive logic theories rely on the conception of "relative truth", with subsequent implications in the way syntax and semantics of formal languages are dealt, which has far reaching consequences in practical applications.

representation of economic systems. However, such notation as a language do not have enough expressive power is capturing important assumptions for our analysis assumptions.

3. Conceptual Model of LCA

There are three main types of actors involved in the process of modelling and use of the LCA methodology: the LCA expert, the final user (i.e. the client of LCA expert) and a specialised software system. Footprint numbers are co-produced by the LCA-expert and the software system: the LCA expert detains tacit expert knowledge and skill, while codified knowledge and routine calculation tasks are delegated to the ICT system (Collins, 2012). All actors involved need to align their "worldviews" in order to engage with an LCA study. The "worldview" of the ICT system is precisely and explicitly codified, in the course of another similar modelling process, in which developers of LCA methodology, mathematical modellers and software developers had needed to align to a shared "worldview". The conceptual model of LCA is this latter "worldview" declared.

The codified "worldview" of the ICT system cannot be changed in the course of an LCA study, so it is the LCA expert and his client which need to adapt their "worldviews" to the one codified in software. Various guidelines and scientific papers in the literature provide useful input in order to help LCA experts in adapting their "worldviews" to those codified in software and in various standards. However, often LCA literature is limited to intuitive explanations, which make explicit only some of the relations between concepts used in the underlying modelling paradigm.

The main concepts employed in LCA are those of economic systems and their configurations to satisfy exogenous demands (those configurations, as we shall see later are exactly what is meant by "product life cycles").

LCA literature traces back the origins of LCA to energy analysis, which on its turn is influenced by economic theory and most notably by Input Output Analysis (IOA). The origins of the ideas behind IOA can be traced back to applications of centralised planning of an economy (ten Raa, 1990). Even though LCA as a tool is not intended for planning applications, the process of configuring an economic system to exogenously given (unconstrained) demand levels is central to the calculation of footprints. Such calculation process certainly bears planning elements, and it is not surprising that literature often report alternative uses of LCA as a tool for governance of entire supply chains (Freidberg, 2014).

3.1 Economic systems

The composite concept of economic system is central to LCA. Its conceptualised through the relation of other simpler concepts of products, flows, and processes.

Economic systems are represented as set of interconnected processes, defined in terms of input and output commodity and environmental flows (Heijungs, 1997; Heijungs and Suh, 2002). The basic assumptions behind LCI conceptual model are the same, as in the open model for IOA (Christ, 1955), that is:

1) Constant proportions between levels of output and input flows, i.e. single observation in time is sufficient to obtain estimation of all parameters in the process representations.
2) Each product is determined uniquely by a process, which produces it. In other words, if a process produces more products, then they are in constant proportions and one of them can be identified as primary product, while the other products must be primary products of other distinct processes.

These assumptions lead to (a) a condition of non-substitutability of inputs – a change in input proportions of a process leads to the "creation" of a distinct product and its corresponding production process and (b) the level of primary output determines uniquely the level of all inputs and other outputs of a process.

More precisely, an economic system S[2] can be defined by means of ordered sets C, E and P of respectively n products (i.e, names of commodities or services), m environmental interventions (i.e. names of environmental flows) and n processes. Each product and environmental intervention is associated with unique measurement unit, which allows expressing levels of flows of the corresponding types. Each process $\overline{p_\iota}$ is represented as an ordered $n + m$ tuple of numbers, standing for commodity or environmental flows:

$$\overline{p_\iota} = \langle c_1^i, \dots, c_n^i;\ e_1^i, \dots, e_m^i \rangle,$$

where:

- Positive numbers indicate output flows (i.e. levels of produced products or emissions to the environment). Negative numbers indicate input flows.
- The primary commodity output of $\overline{p_\iota}$ is the i-th product p_i and the flow $0 < c_i^i \leq 1$ denotes a fraction its primary unitary output flow, which is not used within the process itself as input.
- $c_j^i < 0\ (i \neq j)$ are constant efficiency coefficients expressing levels of input commodities necessary for the production of a unit of the primary output.
- $c_j^i > 0\ (i \neq j)$ are constant ratios of secondary outputs produced together with a unit of the primary output.
- e_k^i is a constant ratio between so-called environmental interventions and the unitary primary output.

A detailed account of how the above conceptual structures relate to both methodological and computational/mathematical issues about LCA can be found in (Stefanova and Iannetta, 2016)[3].

3.2 Demand-centric configuration of economic systems

Demand for a particular product or mix of products, is another concept central in both the contexts of LCA and IOA. In LCA, quantities of two or more products of the system can be equalised on the base of the same level of demand for a function. Such demand levels are expressed in terms of functional units, defined exogenously. The central problem of the LCA inventory analysis is: given a demand level for a product and a representation of an economic system find a configuration of the system which satisfies the demand level of the product (Heijung and Suh, 2002). Life Cycles of a product are exactly these demand-centric configurations of economic systems. In such configurations the intermediate commodity outputs are adjusted in such as way, as to satisfy the demand level for the product by following backwards the output-input links. Life Cycles are possible to define, only under the assumptions discussed in section 3.1. More precisely, the life cycle of a product p_i with respect to an economic system S and a functional unit f is a n-tuple:

$$LC_f^S(p_i) = \langle o_1 \times \overline{p_1}, \dots, o_n \times \overline{p_n} \rangle\ ,$$

where o_j are the levels of primary outputs of each process in the system scaled-up to match the external demand level for p_i (for complete details see Stefanova and Iannetta, 2016). Processes of S, which do not participate in the life cycle of the product p_i will be null-valued process tuples.

[2] In the sequel, tuples of numbers will be denoted by a denoted by over-lined letters; scalars and names – by small letters, more complex structures and sets – by capital letters.
[3] Available upon request from the authors.

3.3 Environmental performance

In LCA a system perspective is adopted for measuring environmental performance. In fact, for each impact category LCA makes use of conjoint measurement functions with additive composition rule, which have the following form:

$$I_f^S(p_i) = \sum_{j=1}^{n} o_j \times I(\overline{p_j}),$$

where $I(\overline{p_i})$ are the impact measurement functions per unit primary output flow for each process in the system.

4. Mediterranean Diet and LCA

This section discusses the conceptual model of LCA in connection of two conceptions of the notion for Mediterranean Diet. In the first case, LCA can be used in analysing options under demand-restrained perspective, and consequences of such options on land use or trade intensity patterns. The second conception of Mediterranean Diet refers to a model of relations characterising the peasant way of farming (van der Ploeg, 2008) and can be adopted in analysing options under system transformation perspective.

4.1 Conceptions of the Mediterranean Diet

The notion of Mediterranean Diet can be perceived in two ways.

First, it is associated with a healthy nutritional model, successfully disseminated across the world through the Mediterranean Diet pyramid (Bach-Faig et al., 2011). The term itself had been coined by the American physiologist Ancel Keys, in order to capture typical dietary habits occurring among poor rural population in the 1960ies in several ecological zones from the Mediterranean Basin (Trichopoulou et al., 2014). The *traditional* Mediterranean diets have been expiring case studies for understanding numerous relations between nutrition and health. Such studies employ the dietary pattern concept, which, abstracting from spatio-temporal contexts and the corresponding food systems, allows capturing such characteristics of a diet, which are of interest to health and nutrition professionals. For this reason, specific dietary patterns often need to be updated in order to accommodate changes in other food characteristics, which can impact health (Trichopolou et al., 2014).

A second interpretation is connected with the recognition of the Meditteranean Diet as a cultural heritage by UNESCO. “The Mediterranean Diet – derived from the Greek word *díaita*, way of life – is the set of skills, knowledge, rituals, symbols and traditions, ranging from the landscape to the table, which in the Mediterranean basin concerns the crops, harvesting, picking, fishing, animal husbandry, conservation, processing, cooking, and particularly sharing and consuming the cuisine” (Unesco, 2013). In this conception the Mediterranean diet encompasses more than just food, it makes reference to the entire food system which delivers it and it puts emphasis on social interaction. As mentioned above, *traditional* Mediterranean diets are the diets of poor rural communities from the past (Trichopoulou et al., 2014). As such they are connected with peasant mode of farming, whose distinguished characteristics are tightly connected with presence of difficult conditions in the social context of peasantry, in which such way of farming becomes a “necessary institution” (van der Ploeg, 2008, p. 35).

4.2 Mediterranean Diet and demand-restrained perspective

Recent studies on the environmental impacts of livestock-based products, had brought the attention to potential environmental impact reductions associated with diets low in animal-based products. There are many LCA studies in the literature, carried from demand-restraint perspective, which aim to identify synergies between environmental and health outcomes of food systems (Heller, et al., 2013). Many of these studies consider the Mediterranean dietary pattern as an option for environmental assessment (see the first conception discussed above).

This sub-section discusses five studies from the literature, which employ LCA indicators to measure the environmental performances of Mediterranean dietary patterns (Duchin, 2005; Pairotti et al., 2015; Tilman, 2014; Tukker et al., 2011; van Dooren and Aiking, 2015; van Dooren et al., 2015). In LCA Dietary patterns are represented with the help of mixing processes with an output the mix-product and inputs- the product components of the pattern. Changes of proportions in the mix of products results in the creation of a new process and a commodity representing a different dietary pattern mix of the same product groups. Synergies between health and environmental outcomes are not always reported, since sometimes reduction the contribution of most impacting food-stuffs in a product-mix (i.e. animal-based products) can be offset by the increased contribution of other food-stuffs (see for example Tukker et al., 2011). As a general rule, various product mixes by means of which Mediterranean dietary patterns are represented result with lower environmental impacts, due to the lower shares of animal-based products.

As a general rule, all LCA studies assessing diets take as a reference global production contex. Diversely, the consumption context can be national, regional or global, according to the purpose of the study. For example, studies aiming to define nutritional guidelines recommending healthy and environmentally friendly dietary choices often target national or regional consumption contexts (van Dooren et al., 2014 and 2915; Pairotti et al., 2015). Other studies are more concerned about consequences of diet change on the agricultural sector and shifts in land use patterns. Such kinds of studies propose to consumers less drastic changes in diet (which, most likely are also less healthy), but take into account also industrial interests (Duchin, 2005). For example, the Mediterranean dietary pattern in (Tukker et al., 2009) is defined in terms of the current average dietary patterns of several countries from South-East Europe (Bulgaria, Romania, Greece and Italy), which is less impacting for the life-stock sector than Mediterranean patterns recommended by health professionals (Bach-Faig et al., 2011). Yet, other studies explore regional differences in technological efficiencies in the production of the same products and consider impacts on trade flow intensities (Tilman and Clark, 2014). The consumption context of such studies is global. (Duchin, 2005) defines a modeling framework, which allows to assess in a consistent way options for change in technological efficiencies, consumption demand (diets), and trade intensities between regions on a global scale.

4.3 Mediterranean Diet and system transformation perspective

According to the second conception above, the Mediterranean Diet can be regarded as a model of relations characterising the peasant-mode of farming and induced by it market and consumption relations (van der Ploeg, 2008). As such it could be regarded as an idealistic reference model for guiding food system transitions in the Mediterranean Region. Such idea-based models are useful artefacts in studies, where modelling is employed for the purpose of re-design of systems of human activities (Checkland, 1995). This kind of modelling puts more emphasise on alignment of concepts and relations between actors involved, since empiric observation is possible only for present state of the systems. In fact, involved actors must understand which are important characteristics real-world systems to be empirically observed and modelled when making reference to a “desired-to-be-futures”.

Peasant production mode is characterised by (a) co-production with nature and self-controlled resource base, (b) learning and (c) social interactions (van der Ploeg, 2008, p. 26). This section assumes that these characteristics are considered relevant under the system transformation perspective. The aim is to show that they pose a representational challenge to the assumptions of a primary output and fixed coefficient ratios adopted within the conceptual model of LCA.

Each production cycle in peasant-mode production is built upon resources (natural and social) that are produced and re-produced during previous cycles. This feature alone is challenging in terms of LCA, as change in efficiencies or substitution in inputs can be only represented by introducing distinct processes and products (see Section 3). From purely pragmatic point of view it seems unfeasible to add a distinct process for each production cycle in this type of farming.

Second, representation of peasant farming inputs in terms of LCA is also problematic. The main types of inputs here are from nature (i.e., ecosystem services) and from humans (labour and knowledge) (van der Ploeg, 2008). In the modelling framework of LCA, only marketable inputs from other production processes (or sectors) are considered and that is why the assumption of fixed coefficients ratios to primary output can seem plausible. Applying it to inputs from nature and to knowledge inputs does not look easy, also because our knowledge on both nature and humans is not so precise to be expressed in so simple way.

Third, representation of outputs is problematic too. The outputs of this type of farming are not only marketable products and undesired outputs to nature, but also desired outputs to nature, knowledge as well as construction of a style of farming which determines the relationships with markets and consumers (van der Ploeg, 2008, p. 26). In particular, reproduced production factors and outputs, not delivered to the market, are variable and cannot be handled by extending the framework of fixed ratios of secondary outputs to primary commodity output (van der Ploeg, 2008, p. 44). Furthermore, it is difficult to identify a unique primary output such farming modes of production.

Fourth, also the concept of exogenous demand, adopted in LCA by making reference to functional units is problematic. Peasant-mode of production is characterised by limited resource base per unit of product. This clearly poses a constraint on the demand to a system, and the concept of a life cycle, being a configuration of a system to an exogenous unconstrained demand needs re-consideration.

5. Discussion

Being far from claiming a completeness analysis of the traditional Mediterranean model for production and consumption, as shown in Section 4.3 assessing options under system transformation perspective could be extremely challenging in terms of LCA. This section discusses some fundamental assumptions about empirically observable systems, implied by the performance measurement functions of LCA (see Section 3.3) and the conditions defining relations between concepts within its conceptual model (see Section 3.1). On the base of this and the analysis in Section 4.3, a generalisation of the performance measurement functions is proposed, which avoids some of the identified representational problems.

5.1 Independence assumption

The additive composition rule (see Section 3.3) implies preferential independence assumption among components (phases) of the observable economic systems (Krantz et al., 1971). Note that such independence can be only assumed and not validated through empiric observations. In fact, economic system representations in LCA are cognitively related to observable systems of human activities, but unlike models used in classical sciences, footprints calculated out of them cannot be experimentally validated (Heijungs, 1997). Therefore a preference relation between observable systems cannot be empirically established in order to check whether or not preferential independence condition holds (see Krantz et al., 1971).

Independence is a very strong assumption, which is often hard to demonstrate empirically and enters often in debates of correctness in using additive aggregation rules in MCDA (see Nardo et al., 2005). What does it mean, in LCA setting? A subset of two or more phases from the observable economic system are assumed to remain in the same preference order with respect of their e.g. climate impacts, whatever are the corresponding impacts of the rest of system stages. That is, no matter how we improve and optimise the agricultural phase of a food chain, the rest of the phases can be ordered for their impacts in the same way as before optimisation happened at farm level.

The independence assumption at empirical level is tightly connected to both the use of LCA and to the way concepts are related in its conceptual model. In fact, even if each LCA-study adopts a live-cycle perspective, options compared by it concern only single system stages. The rest of the system remains the same, while corresponding flows are adjusted to satisfy a new level of production due to a change in technological efficiencies.

The additive composition and independence assumption imply also a compensatory logic and existence of trade-offs between processes participating in the life cycle of a product (Nardo et al., 2005). That is, if for example a phase in a food chain is very efficient (e.g. distribution or large-scale industrial production), it can offset inefficiencies at other phases (e.g. agricultural phase). Such inefficient phases can be identified by performing LCA for hot-spot analysis. Thus, consecutive substitutions of single processes with more efficient options can result in an optimisation process, facilitated by the use of LCA, which aims at **trade-offs minimisation**. Offsetting disadvantages and compensatory principles are applied also when the goal is to identify optimal product mixes as in the cases discussed in Section 4.2.

The independence assumption is incorporated in the conceptual model too in the form of two assumption: (a) primary output products and (b) fixed ratios of other inputs and outputs to primary output. That is, if two processes deliver comparable products with different efficiencies, substitution of one of them in the corresponding life cycle, do not lead to change of input/output rations in other processes (only corresponding quantities are adjusted). The argument extends also to situations of input substitutions as for example in the case of organic and conventional agriculture. In this case we have more than one processes affected, which are independent of the rest (see Nardo et al, 2005, p. 75).

These two conditions at level of conceptual model, as Section 4.3 shows are problematic in considering options under system transformation perspective.

5.2 Generalised performance measurement functions

Based on the analysis in Section 5.1 and identified representation gaps within the conceptual model of LCA (Section 4.3), this subsection propose a generalised form for the performance measurement function. It is generalised in two ways. First, by allowing assumptions of interdependencies between system parts. Second, the modelling paradigms can be chosen according to characteristics considered relevant for the purpose and consistent with "desired-to-be-futures". In fact, the term sustainability is carrying a reference to the future, which makes it both ambiguous and difficult to measure (Chekland, 1995).

Suppose an economic system can be defined in terms of n components $p_1, \dots, p_n$. A general form for impact measurement function can be expressed by:

$$I(\langle p_1, \dots, p_n \rangle) = F\left(I_1(p_1), \dots., I_1(p_1)\right).$$

The measurement function above generalises LCA in two ways: first, it is not necessary to define the measurement functions of each system component in terms of the same modelling paradigm and second, in order to calculate system performance, it is not necessary to use additive composition rule. For example, a function for sustainability performance for Mediterranean Diets from different agro-ecological zones, using geometrical mean composition functions have been proposed in (Iannetta, 2012). While the challenge of finding appropriate measurement functions in order to consider and asses options prioritised under the system-transformation perspective remains open, the generalised measurement function can be useful in two ways. First, the scientific base of LCA can be clarified better, in terms of conditions, properties and assumptions, if examined in relation to measurement theory (Krants et al., 1971). Second, reference to well developed theoretical frameworks could provide a further step in the development of approaches for sustainability analysis, which differentiate between subjective assumptions and objective procedures based on them, allowing thus to consider multiple stakeholder's perspectives.

References

Bach-Faig, A., Berry, E.M., Lairon, D., Reguant, J., Trichopoulou, A., Dernini, S., Medina, F.X., Battini, M., Belahsen, R., Miranda, G. & Serra-Majem, L. (2011). *Mediterranean diet pyramid today. Science and cultural updates*, Public Health Nutrition, 14(12A), 2274–2284.

Brodie, M. (2009). *John Mylopoulos: Sewing Seeds of Conceptual Modelling*, in A.T. Borgida et al. (eds), Mylopoulos Festschrift, LNCS.

Collins, H.M. (2012). *Expert Systems and the Science of Knowledge*, in Bijker et.al. (eds), The Social Construction of Technological Systems, New Directions in the Sociology and History of Technology. The MIT Press, Cambridge, Massachusetts, London, England.

Checkland, P. (1995) *Systems theory and management thinking*. In: Ellis et al. (eds), Critical Issues in Systems Theory and Practice, Springer Science+Business Media New York.

Christ, C.F. (1955). *A Review of Input-Output Analysis.* In: *Input-Output Analysis: An Appraisal,* Princeton University Press. Available online: http://www.nber.org/chapters/c2866 (accessed on 27 03 2016).

Duchin, F. (2005). *Sustainable consumption of food: a framework for analysing scenarios about changes in diets*, Journal of Industrial Ecology, v.2: 1-2.

EC (2013*). Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations: PEF and OEF guides*.

Freidberg S. (2014). *Footprint Technopolitics*, Geoforum, 55: 178-139.

Galatola, M.; Pant, R. (2014). *Reply to the editorial "Product environmental footprint—breakthrough or breakdown for policy implementation of life cycle assessment?" written by Prof. Finkbeiner (Int J Life Cycle Assess 19(2):266–271*). International Journal of Life Cycle Assessment,19:356–1360.

Galli, F.; Bartolini F.; Brunori G. (2016). Handling Diversity of Visions and Priorities in Food Chain Sustainability Assessment, Sustainability, 8(4), 305; doi:10.3390/su8040305.

Garnett, T. (2014). *Three perspectives on sustainable food security: efficiency, demand restraint, food system transformation. What role for Life Cycle Assessment?* Journal of Cleaner Production, 73:10-18.

Geoffrion, A.M. (1987). *An introduction to structured modeling*, Management Science, 33, No.5, 547-588.

Guinée, J. B.; Heijungs, R.; Huppes, G.; Zamagni, A.; Masoni, P.; Buonamici, R.; Ekvall, T.; Rydberg, T. (2011). *Life Cycle Assesment: past, present, and future*. Environmental Science and Technology, 45: 90-96.

Heijungs, R. (1997). Economic drama and the Environmental stage: formal derivation of algorithmic tools for environmental analysis and decision-support from unified epistemological principle, Ph.D. Thesis, Rijskuniversiteit te Leiden, Leiden, the Netherlands.

Heijungs, R.; Suh S. (2002). *The Computational Structure of Life Cycle Assessmen*t; Kluwer Academic Publishers: Dordrecht/Boston/London.

Heiskanen, E. (2000). *Managers' interpretation of LCA: enlightenment and responsibility or confusion and denial?*, Business Strategy and the Environment, 9: 239-254.

Heller, M.C., Keoleian, G.A. & Willet, W.C. (2013). *Toward a life cycle-based, diet-level framework for food environmental impacts and nutritional quality assessment: a critical review*. Environmental Science and Technology, 47(22): 13632–13647.

iPES FOOD (2015). *The new science of sustainable food systems, Overcoming barriers to food systems reform. Report 01, International panel of experts on sustainable food system*s. Available online: http://www.ipes-food.org/reports (accessed on 03 12 2015).

Krantz, D.H.; Luce R.D.; Suppers P.; Tversky, A., (1971). *Foundations of measurement, Vol.1 Additive and Polynomial Representations*, Academic Press, New York and London.

Iannetta, M. (2012). *Expert system for evaluating the sustainability of Mediterranean diets by an integrated product index (IPI-SMeD) in a specific agro-ecological zone*. Options Méditerranéennes, Series B: Studies and Research, No. 70. CIHEAM.

Johnson-Laird, P. (1983). *Mental Models: Towards a cognitive science of language, inference, and consciousness*, Cambridge: Cambridge University Press.

Minski, M.L. (1968). *Matter, Mind and Models*, in Semantic Information Processing, M. L. Minski Ed. Publisher: MIT Press. Available online: http://web.media.mit.edu/~minsky/abstracts.html (accessed on 22 December 2015).

Nardo, M.; Saisana, M., Slatelli, A.; Tarantola, S. (2005). Knowledge Economy Indicators, Input to Handbook of Good Practices for Composite Indicators' Development, FP6, CIS8-CT-2004-502529 KEI, Deliverable 5.2.

Pairotti, M.B.; Cerutti, A.K.; Martini, F.; Vesce E.; Padovan D.; Beltramo, R., *Energy consumption and GHG emissions of the Meditteranean Diet: a systemic assesment using hybrid LCA-IO method*. Journal of Cleaner Production, **2015**, 103, 507-516.

Partridge, C., Gonzalez-Perez, C., Henderson-Sellers, B. (2013). *Are conceptual models concept models?.* In Ng, W et al. (eds), Conceptual Modelling, ER 2013, LMCS 8217.

Stefanova, M.; Iannetta, M. (2016). *Food system transformation: can LCA help?* TR BIOAG-P000-001, ENEA-Bologna.

Suh, S.; Huppes, G. (2005). *Methods for Life Cycle Inventory of a product*, Journal of Cleaner Production, 13, 687-697.

Ten Raa, (1990). *National accounts, planning and prices.* Nieuw Archief voor Wiskunde (Serie IV), 8(3),375-385.

Tilman D.; Clark, M. (2014). *Global diets link environmental sustainability and human health*, Nature, vol. 515.

Trichopoulou, A.; Martinez-González, M.A.; Tong, T. Y.N.; Forouhi, N. G.; Khandelwal, S.; Prabhakaran, D.; Mozaffarian, D.; de Lorgeril, M. (2014). *Definition and potential health benefits of the Mediterranean Diet: views from experts around the world,* BMC Medicine, 12:112.

Tukker, A., Goldbohm, R.A., de Koning, A; Verheijden, M.; Kleijn, R.; Wolf, O. Pérez-Domiguez I; Rueda-Cantucge, J. (2011). *Environmental impacts of change to healthier diets in Europe*, Ecological Economics, 70:1776-1788.

UNESCO (2013). Mediterranean Diet, http://www.unesco.org/culture/ich/en/RL/mediterranean-diet-00884 (accessed on 25 March, 2016).

Van der Ploeg, J.D. (2008). The new peasantries. Struggle for autonomy and sustainability in an era of empire and globalisation, FiSH Books.

van Dooren, C.; Aiking, H. (2015). *Defining a nutritionally healthy, environmentally friendly, and culturally acceptable Low Lands Diet*, The international journal of Life Cycle Assessment, 10.1007/s11367-015-1007-3.

van Dooren, C.; Marinussen, M.; Blonk, H.; Aiking, H.; Vellinga, P. (2014). *Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns*, Food Policy 44:36-46.

Wezel, A., Bellon, S., Dore, T., Francis, C., Vallod, D., David, C. (2009). *Agroecology as a science, a movement and a practice*. *A review*. Agr. for Sustainable Development 29, 503-515.

Wilmont, I.; Hengeveld, S.; Barendsen, E.; Hoppenbrouwers, S. (2013). In Ng, W et al. (eds), Conceptual Modelling, ER 2013, LMCS 8217.