EUFORIE
European Futures for Energy Efficiency

Report on costs of solutions, initial findings and work in progress

Work Package 3 - Deliverable 3.2

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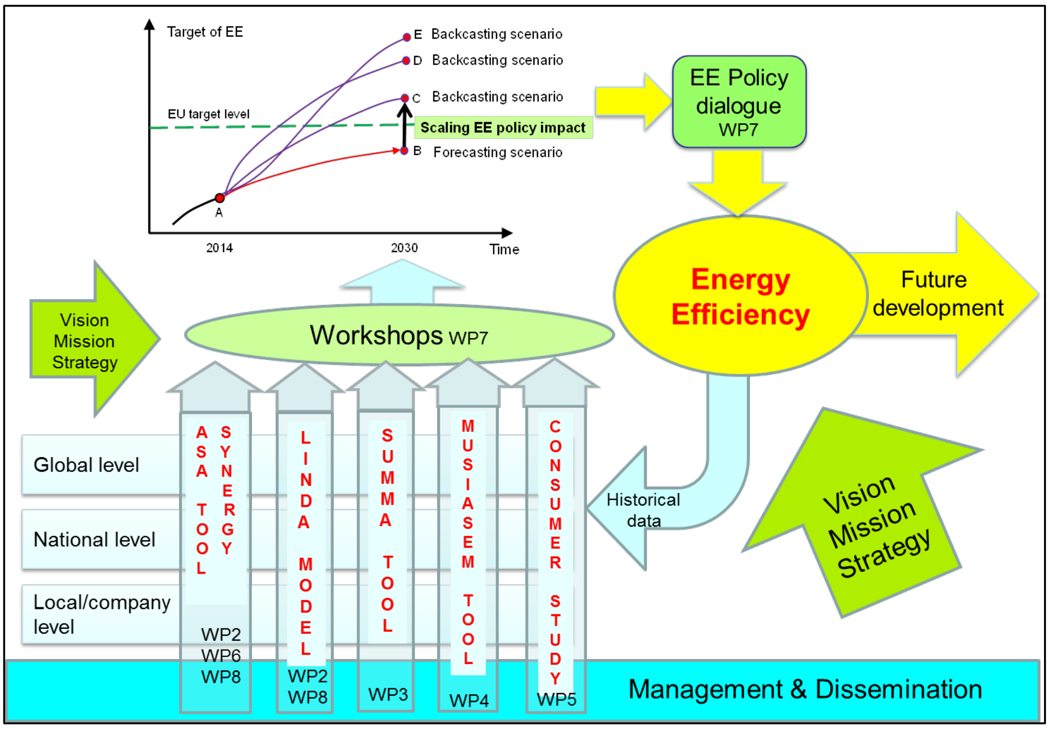
The EUFORIE project

The strategic goal of the EUFORIE project is to provide useful and accurate information and knowledge in the field of energy efficiency for the EU Commission and stakeholders in the Member States. The tangible objectives are the following:

1. To provide energy and energy efficiency trends and their drivers, synergies and trade-offs between energy efficiency related policies, as well as energy efficiency scenarios (WP2).
2. To provide data about implementation of energy efficiency in specific processes, sectors and entire systems, in order to understand bottlenecks/efficiency drops and suggest improvements (WP3).
3. To carry out analyses of efficiency of provision, from making useful energy carriers from primary energy sources, and from conversion of energy carriers to end uses across macro-economic sectors (WP4).
4. To identify policy instruments and other measures leading to significant reduction in the energy consumption of households (WP5).
5. To analyse the relationship between investments and change in energy efficiency, and to develop indicators to describe changing energy efficiency at the company level (WP6).
6. To carry out participatory foresight for European stakeholders of energy efficiency with a target of providing ideas for the energy efficiency vision and strategy in the European Union (WP7).
7. To compare energy efficiency policy instruments and measures and their impacts in China and the European Union (WP8).

The EUFORIE Work Packages relate to each other The project applies different quantitative and qualitative analysis methods to energy efficiency in the EU and its Member States at different levels and from different perspectives. These analyses provide input for foresight activities, which serve European energy efficiency vision and strategy process by generating useful information. Management (WP1) and dissemination (WP9) run in parallel with the research and innovation activities.



Key findings and summary for stakeholders

The main issues raised in this deliverable are:

1. Maximizing energy efficiency is not always the best strategy, in that processes are not only driven by energy.
2. Other resources are crucial, such as water and rare earths, to quote some, which calls for simultaneous minimization of a set of input resources, including energy.
3. At the same time, minimization of impacts, which are not linearly linked to energy consumption, is also a key strategy.
4. Efficiency maximization most often affects process time in so decreasing power output.
5. Resources and energy used are not only characterized by amounts, but also by their environmental quality and renewability. These factors affect the quality and the yield of the process and call for a deeper and more comprehensive understanding of the interplay of input and output flows.
6. As a final consequence, optimization, not maximization, is the best option, in order to maximize power output by appropriate tuning of input resources and output flows (yield, co-products, emissions).
7. It is possible to design an assessment tool that joins a selection of evaluation approaches and allows a comprehensive assessment of key environmental and resource issues in a process. Such a tool may support collaborative and participatory interaction among stakeholders and policy makers, conflict prevention, and appropriate environmental management.

This deliverable stresses three main aspects:

a) the extended meaning of the concept of "cost": non only economic cot, but also resource and environmental cost;
b) the need for a performance optimization strategy rather than an efficiency maximization strategy;
c) possibility to design a tool in support of participatory strategies. The tool would ease the evaluation of alternative options and would generate scenarios, in support of policy making.

List of tables

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Updated list of EUFORIE related papers, published to date.

1. Gabriella Fiorentino, Maddalena Ripa and Sergio Ulgiati, 2016. Chemicals from biomass: technological versus environmental feasibility. A review. Biofuels, Bioproducts and Biorefining, 11: 195-214.

1. Elvira Buonocore, Salvatore Mellino, Giuseppe De Angelis, Gengyuan Liu, and Sergio Ulgiati, 2016. Life cycle assessment indicators of urban wastewater and sewage sludge treatment. Ecological Indicators, Available online 20 May 2016, ISSN 1470-160X, http://dx.doi.org/10.1016/j.ecolind.2016.04.047, (http://www.sciencedirect.com/science/article/pii/S1470160X16302291).

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3. M. Ripa, G. Fiorentino, V. Vacca, S. Ulgiati, 2017. The relevance of site-specific data in Life Cycle Assessment (LCA). The case of the municipal solid waste management in the metropolitan city of Naples (Italy). Journal of Cleaner Production, 142(1): 445-460.

4. Antonio Puca, Marco Carrano, Gengyuan Liu, Dimitri Musella, Maddalena Ripa, Silvio Viglia, Sergio Ulgiati, 2017. Energy and eMergy assessment of the production and operation of a personal computer. Resources, Conservation and Recycling, 116: 124-136.

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6. Ghisellini P. and Casazza M., 2016. Evaluating the energy sustainability of urban agriculture towards more resilient urban systems. Journal of Environmental Accounting and Management, 2016, 4(2): 175-193.

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8. Xu Tian, Yong Geng, Sergio Ulgiati, 2017. An emergy and decomposition assessment of China-Japan trade: Driving forces and environmental imbalance. Journal of Cleaner Production 141: 359-369.

9. Yong Geng, Xu Tian, Joseph Sarkis, Sergio Ulgiati, 2017. China-USA Trade: Indicators for Equitable and Environmentally Balanced Resource Exchange. Ecological Economics 132: 245–254

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pubblication, doi: 10.1016/j.jclepro.2017.08.171, online 20 August 2017, http://www.sciencedirect.com/science/article/pii/S0959652617319030.

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13. Hornsby, C., Head, N., Ploumistou, E., Ulgiati, S., 2017. Cross-Cultural Assessments and Stakeholder Consultancy towards Resource Waste Reduction and Climate Change Prevention. SOJ Symbiosis Online Journal - Psichology. https://symbiosisonlinepublishing.com/psychology/. Open Access. Pp. 1-22.

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14. Corcelli F., Ripa M., Ulgiati S., 2017. Efficiency and sustainability indicators for papermaking from virgin pulp. An emergy-based case study. Submitted to the Journal Resources, Conservation and Recycling.

15. Shupei Huang and Sergio Ulgiati, 2017. Terrestrial transport modalities in China: a survey of monetary, energy and environmental costs. Submitted to Transport Policy, https://www.journals.elsevier.com/transport-policy.

16. Ghisellini P., Ripa M. and Ulgiati S., 2017. Material Efficiency in Buildings and related energy savings. Exploring environmental and economic costs and benefits of a circular economy approach to construction and demolition materials. Submitted to Journal of Cleaner Production.

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BOX 1 – Tasks of WP3 related to Deliverable D3.2

WP 3: Regional case studies of energy efficiency in Europe (from the proposed project, slightly modified according to later agreements with the Coordinator)

Task 3.4. Cost of solutions.
The efficiency of investigated case studies and their critical steps (efficiency drops) will be discussed with involvement of stakeholders and multicriteria experts, in order to understand solutions (if any) for higher energy efficiency. Solutions do not come for free. Environmental, material and energy costs and benefits, constraints and barriers to the implementation of solutions will be assessed (through LCA, emergy, MuSIASEM methods) with special attention to burden shift prevention. The energy cost for implementation of a given innovation may be higher that the energy benefits, or the environmental or social constraints may suggest to redesign or replace a given step or process.

Deliverables:

Deliverable 3.2: Report. Costs of solutions, initial findings and work in progress. Delivery: Month 26.

BOX 2 – Tasks of WP3 related to the next Deliverables D3.3 and D3.4

Task 3.5. Large spatial and time scale cost and benefit assessment.
Identification of local or specific efficiency drops or improvements does not necessarily mean that the same consequences or solutions apply Europewide. The extension of the analysis and of the solutions to the larger national scale or to the EU scale over time will be performed, through geographical exploration of needs, potentials and constraints (via GIS mapping). Design of scenarios of benefits over time, through the ASA model, will be performed.

Task 3.6. Standards for assessments.
Exploring the potential integration of the different approaches into a standard procedure for policy making. Testing the synergic effect of providing a multiplicity of indicators designed for different purpose. Pointing out the added value of results confirmed by more than one approach, but also of results that some methods are unable to identify, while other do. In so doing a comprehensive and bold basis for policy can be provided.

Deliverables

Deliverable 3.3: Report. Assessment of costs and benefits of energy efficiency solutions suggested and modelled in Tasks 3.4 and 3.4. Delivery: Month 34

Deliverable 3.4: Report. Standardization and integration of assessment methods focused on energy efficiency. Delivery: Month 38. Responsible: Parthenope University.

Executive Summary

The goals of this deliverable

In the previous WP3 Deliverable (D3.1) we have shown and discussed a number of case studies characterized by different spatial and time scale as well as activity sector, of which we have assessed the yearly performance in terms of relation of input flows with yield and airborne, waterborne and solid emissions. Some of these flows were measured in actual energy terms and units (joule, kcal, oil equivalents), while others were clearly expressed as mass or monetary flows. Our point was that not only energy efficiency is crucial to the full understanding of a process or system's dynamics, but also other categories of driving forces, including ecosystem services, material flows, monetary flows. Optimization, not maximization, of their use compared to the achieved or intended yield should the final goal of economic and environmental policy. If this is the goal, it can only be achieved by means of transparent use of all process data and information and their analysis and discussion between policy makers and stakeholders within a participatory strategy aimed at conflict prevention and maximization of benefits and wellbeing.

The goal is to provide the basis for a transparent discussion that goes beyond mono-dimensional choices (e.g. maximizing energy efficiency) and embraces a comprehensive set of consequences (resource depletion, environmental impacts) investigated thanks to the synergic application of selected environmental assessment tools (LCA-Life Cycle Assessment, GIS-Geographical Information System, EMA-Emergy Accounting, MFA-Material Flow Accounting), each one characterized by appropriate scale, objective and design. Considering that the EUFORIE project involves teams with huge expertise in Advanced Sustainability Analyses (ASA, Turku Univ, Finland), Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM, UAB Spain), Sustainable Consumption and Sustainability Analysis (SERI, Germany), the proposed tool is likely to undergo in the rest of the EUFORIE project a further integration with a number of approaches capable to provide a full understanding of the options at stake and the performance drops and potential improvements.

The contents of this Deliverable

In the present deliverable we stress the "optimization versus maximization" aspect and suggest the possibility to design a tool for performance assessment of processes, that can be used by policy makers and stakeholders in order to understand costs & benefits associated to different available or potential alternatives.

The "optimization versus maximization" issue is carried out based on basic thermodynamic thinking derived from Odum, Prigogine, Onsager and their irreversible thermodynamic research applied to biological and technological systems. We clarify, also with reference to the previous D3.1, that "energy efficiency" needs to be complemented by a much larger set of concepts (material efficiency, time and spatial scales, supply-side and user-side resource quality, sensitivity and uncertainty analyses) in order to achieve the global goal of sustainable production and consumption at local and larger scales.

In the present deliverable, a discussion about the characteristics of the proposed monitoring, assessment and management tool is carried out, with examples suitable for testing. Further research in expected to lead to a prototype design and calculation procedure as well as a number of tested cases. The expected result is to generate a support framework and basis for participatory strategies and collaborative interaction among policy makers and stakeholders.

INTRODUCTION

1. The intended meaning of "cost assessment"

WP3 looks at assessing costs and benefits of implementing energy and material efficiency. In the previous Deliverable D3.1 we have presented and described the methods to be used for the study (Cumulative Energy Demand-CED, Life Cycle Assessment-LCA and Emergy Accounting-EMA) and a number of case studies at different spatial and time scales, investigated by means of the above methods. The goal in D3.1 was:

a) to create a sufficiently broad database of resource use in selected production sectors, to become the working material for the next work packages that aim at developing a framework and preliminary calculation procedures of costs and benefits achievable under an energy and material efficiency focus;

b) to show that the selected methods CED, LCA and EMA provide a sufficient, although not unique, approach to the discussion, the understanding and the management of the resource efficiency aspects within local, regional, national and EU production sectors and economies. The main goal was to create the basis for method integration, starting from the selected set of biophysical approaches and expanding to other methods and points of view developed by the EUFORIE project Partners and beyond.

The present deliverable D3.2 aims at designing the basic concepts of and identifying constraints to an innovative cost assessment capable to go beyond monetary evaluation and span over a comprehensive overview of the problems involved in energy and material efficiency, while the next Deliverables D3.3 and D3.4 will go deeper into the way an integrated procedure can be developed and applied, to support scenario and policy making.

The term "cost" is not intended in the WP3 as a synonymous of "monetary cost". It is well known and widely accepted worldwide that monetary costs are not a sufficient assessment of the investments and the impacts of a process or an economy. No need to spend too many words to point out that market driven monetary costs - although unavoidable and not to be disregarded

- are too dependent on contingent events, political strategies, alliances, and also short-sight plans. Figure 1 shows the historical trend of oil prices from the year 1973 to date. Since the 1973 oil crisis and throughout the following strategic management of oil resources, oil prices have always been used as a way to affect international policies and interfere with decision making, alliances, internal and international stability aspects. Very seldom, if any, oil prices have been dictated by scarcity, perspectives of the energy futures, self-reliance strategies of national economies, different environmental and thermodynamic quality of resources, or even environmental concerns. Every important change in the Figure 1 diagram can be associated to international political turmoil more than to increased understanding of the sustainability of oil ability to drive the future of our planet. Similar considerations can be made for other fossil fuels, for nuclear energy (where the military option and national status play a huge role), for minerals (just think of the internationals arguments about "rare earths", especially between China and the USA), water and - last but not least - land. Monetary costs reflect the desire of an economic actor (a Nation, a Corporation, an individual Entrepreneur or an individual citizen) to acquire a resource and support an economic process (either production or consumption), no matter other unintended or side consequences that may be associated to the intended aim of increasing the monetary outcome of the activity or taking advantage of the acquired good.

Figure 1. Historical trend of oil prices

"Cost" in WP3 is not only a monetary cost. The WP3 concept of cost expands to encompass all kinds of upstream and downstream impacts that are associated to a resource entering a production or consumption process. The most common alternative concept of "cost" refers to the energy cost, i.e. the number of joule is takes to make a resource available or to process and deliver a good to a potential user. Markets and political strategies may change the monetary cost but cannot change the amount of energy that is needed to mine, process and convert a kg or bauxite to alluminium or to a manufactured good that is based on alluminium. Although improving technologies may slightly lower the energy cost of alluminium ingots, awareness of the impossibility to escape the energy bill is slowly spreading and becoming a shared understanding.

As upstream impacts we refer to depletion aspects associated to a resource withdrawal and use (from water depletion, fossil fuels depletion, soil erosion & land use change, to the depletion of stocks that used to be renewable - such as fishery and forests stocks - and now are no longer such due to excess extraction). Depletion is a different "cost" aspect, in the broader sense that refers to a situation in which a resource becomes no longer available, similar to situations in which monetary costs increase makes something no longer reachable by a number of potential users.

As downstream impacts we refer to airborne, waterborne and solid emissions that lower the quality of life of a fraction or the totality of a population, due to alterations of the biosphere dynamics (quality of urban areas, quality of drinkable water, quality of cropped soil...). Such impacts, listed as environmental impact categories in LCA, span from global warming potential, eutrophication potential, ecotoxicity and human toxicity potential, acidification, among others, and clearly represent new bills to be paid by societies in order to support economies and lifestyles.

Last but not least, resources are generated by the biosphere dynamics at different speeds and according to different amounts. The biosphere efforts, powered by the main driving forces of solar radiation, deep heat and gravitational potential, provide ecosystems services and their cumulative storages generally referred to as natural capital. Their measure, as an upstream impact category, can be quantified by means of the Emergy Accounting approach (Odum and Odum, 2000) thus providing a biosphere-based footprint that adds to, complements and enriches the monetary evaluation, by providing what is really missing in it, Nature (Figure 2). It is useful here to recall the quote "*Ecosystems of the world are threatened because market prices are used to evaluate them.*" by Odum and Odum (2000).

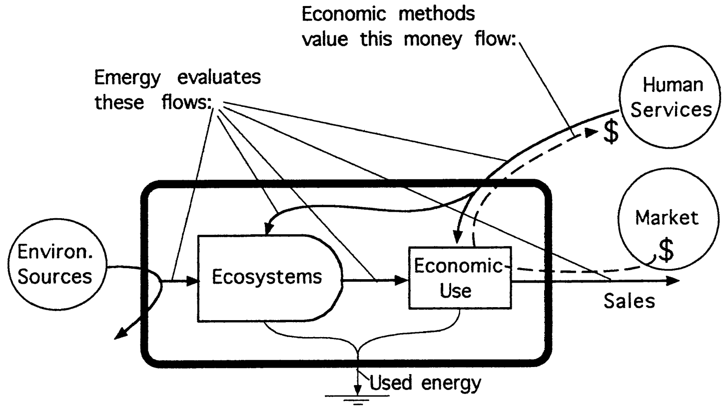

Figure 2. Interface between ecosystems and economics comparing evaluations. Current economic procedures place monetary values only on the market-to-human services flow, whereas Emergy evaluates all of the flows shown. (Odum and Odum, 2000)

As a consequence, energy costs are always associated to a number of additional costs (upstream and downstream impact categories) that may emerge as even more serious than monetary costs or just fossil energy shortage.

The aim of the present research is therefore to be able not only to look at the monetary cost of resources nor to assess the energy cost of a given economic output (GDP, tons of corn, individual goods) nor even what can be saved in energy terms by implementing efficiency patterns, but rather how this energy costs change when the process undergoes changes in resource use, technology, regulatory policies, increased efficiency in terms of either increased output for the same resource input and decreased input of resources for the same output.

2. Material and Energy Efficiency (excerpt from Deliverable D3.1)

This Section 2 is fully extracted from the Deliverable 3.1, in order to keep very clear what are the potential efficiency improvement options and to be the basis for the planned resource and environmental improvement. We recommend a careful reading of this section before moving into the next analytical and optimization steps.

The efficiency concept may be looked at under several different points of view as well as time and spatial scales. Conceptually, efficiency suggests same results (products, services) be achieved with less input flows (material, energy, labor), or, vice versa, better results (more products, more services) be achieved with the same effort (same materials, same energy, same labor). Things may become even more complex from a conceptual point of view if focus is not placed on the amount of input or output flows, but instead (or also) on the quality of input and output flows. This is when, in addition to the raw amounts the assessment looks at the impacts of resource use as well as at their environmental quality or environmental generation dynamics. The WP3 activities have therefore focused on different aspects that can be summarized as follows:

2.1 Energy efficiency: how energy efficiency concepts emerge within a specific case study, process, system. In particular:

2.1.a) Identify which input flows carry more energy and how this can be addressed and decreased (process design improvement, distance from flow source, flow replacement, etc).

2.1.b) Identify which process steps are the most energy demanding and how this can be addressed (process design, distance and transport issues, machinery replacement, etc).

2.1.c) Identify useless steps and options for their removal.

2.1.d) Identify still usable waste energy flows (e.g.: residual heat) and co-generation potential in process (i.e.: adding new co-products).

2.1.e) Identify options to increase the output flow without increasing the input demand, by decreasing waste flows (i.e.: feedback flows, cascade design, etc).

2.2 Material Efficiency: how appropriate material use and recycling affect energy demand. In particular:

2.2.a) Identify reuse and recycling impacts on process energy demand.

2.2.b) Identify material flows that carry the largest embodied energy.

2.2.c) Identify aspects of transport and distance (waste material collection, distance from mines, distance from disposal sites).

2.2.d) identify the most material demanding steps and their improvement potential (to be linked to the point 1.b above, about energy demanding steps).

2.3 Quality Assessment versus efficiency.

Replacement of input and output flows makes the system different and may generate burden shifts or affect the functional unit. In particular:

2.3.a) Replacement of input flows is not just a matter of joules (one joule of oil versus one joule of coal versus one joule of solar), but involves the environmental work to generate a resource (time, ecosystem services, biosphere dynamics. This require focusing on biosphere replacement ability and embodied time. We address this by means of the eMergy method.

2.3.b) Replacement of input flows (be they primary energy, energy carriers or material flows) may help improve efficiency but generate burden shift. This can be addressed by means of Life Cycle Assessment.

2.3.c) Cogenerating two or more co-products, or re-designing a process towards different products or functional units may provide resource and environmental advantages, in that resources may be used more efficiently in a process than in another (e.g.: more efficiently in mass transportation processes than in individual transportation; more efficiently in providing a service – photocopies – than in supplying a product – a copy machine).

2.3.d) Full redesign of economic uses of resources (e.g. platform chemicals from biomass residues instead of platform chemicals from petrolchemistry; recycling of construction materials).

2.3.e) Comparison of performance indicators that are directly related to energy (Cumulative Energy Demand, Fossil Depletion, Carbon Emissions) and environmental performance indicators (eMergy indicators, soil use and soil use change, Water footprint, among others), in order to check if a higher energy efficiency was achieved by means of a burden shift affecting the quality of the surrounding environment. Actually, quantifying the trend of environmental indicators versus improvements of energy efficiency might provide a measure of the “marginal cost” of improving energy efficiency.

3. Maximization versus optimization

Any intensive property of a system, such as a voltage, food concentration, pressure difference, surface tension, temperature gradient, concentration gradient, etc., may be regarded as a thermodynamic force (X_i). Coupled with each force is a generalized flux (J_i), such as electrical current, growth rate, rate of extension of volume or area, flow of heat, etc. It is customary to choose these quantities so that the products J_iX_i have the dimensions of a power:

$$\text{Useful Power input} = P_1 = J_1X_1$$

$$\text{Useful Power output} = P_2 = J_2X_2$$

$$\text{Efficiency} = \eta = P_2/P_1.$$

In a formal thermodynamic system (Prigogine, Onsager) the following relation is valid:

$$TdS/dt = J_1X_1 + J_2X_2 \qquad (1)$$

where dS/dt is the rate of increase of entropy of the system and its surroundings, and T is the absolute temperature. J_1 is the flux into the system under the influence of force X_1; J_2 is the flux output associated with force X_2. This output might be thought of as power stored for future use. In production processes or economic processes, this can be the flux of produced goods or services or economic value (with appropriate units; see Appendix case studies for examples). e The rate of dissipation of power is equal to the useful power input minus the useful power output. Dissipation of power is clearly inversely linked to efficiency. The question is to what extent maximization of efficiency is possible, and how much does this affect the final result of the process, i.e. the power output (amount of output per unit time).

In irreversible thermodynamics flows Js are generally assumed to be linearly related to the driving forces Xs (although this is not fully true and sometimes is simply not true, thus adding to the uncertainty):

$$J_1 = L_{11}X_1 + L_{12}X_2 \qquad (2a)$$

and

$$J_2 = L_{21}X_1 + L_{22}X_2 \qquad (2b)$$

and $L_{21} = L_{12}$ are set to be equal (Onsager reciprocity relation). The L's are called "phenomenological coefficients" and are always related to some physically measurable quantities.

Suppose that our system is also characterized by three empirical constants, *l*, *f*, and *c,* defined as:

- *f*= factor of proportionality relating X_2 and X_1 when J_2=0 (no output flow). When X_1 and X_2 are two different kinds of force, the factor *f* shows how they are related dimensionally;
- *c*= conductivity giving the value of J_2 when X_1 is zero (i.e., when X_1 is zero and a force X_2 is applied to the system, *c* expresses how J_2 and X_2 are related);
- *l*= leakage, giving the value of J_2 when X_2=*f* X_1 and J_2 is zero (i.e. when there is no output of useful power, there may be a certain input flow of energy).

Equations (2a) and (2b) may thus be written as:

$$J_1 = (l+cf^2)\, X_1 + cfX_2 \qquad (3a)$$

and

$$J_2 = -cfX_1 + cX_2 \qquad (3b)$$

where *cf*, the coefficient of X_2 in the equation for J_1 is the same as the coefficient of X_1 in the equation for J_2 according to the above Onsager reciprocity relations.

Odum and Pinkerton (1955), based on the above irreversible thermodynamics concepts by Prigogine and Onsager, have been able to link a process efficiency to the useful power input, to the useful power output and to the speed of a process, according to the Equations:

$$P_2 = cf^2 X_1^2\, R(1-R) \qquad (4)$$

where $R = X_2/fX_1$, the ratio of the driving forces, and

$$\eta = R \,/\, [1+l/cf^2(1-R)] \qquad (5)$$

This is an important result, for Equation (4) shows that for any coupled process which operates on these general principles, the maximum power output (i.e. the ability to compete and survive in competition) is obtained when the ratio of the thermodynamic forces R (after conversion to common units) is equal to 0.5. As a consequence, Equation (5) for efficiency at maximum power output becomes

$$\eta_{P2\ max} = 1/\,[2(1+2l/cf^2)] \qquad (6)$$

Results are diagrammed in Figure 3, where efficiency is related to the ratio R of the input and output driving forces. **Note that regardless of the value of *l*, *c*, and *f*, the efficiency η at P_{2max} may never exceed 50 per cent. This suggests that maximizing power output - which is the**

strategy of sustainable ecological systems - does not necessarily require maximizing efficiency, but depends on the specific situation a system is facing in relation to the available resources.

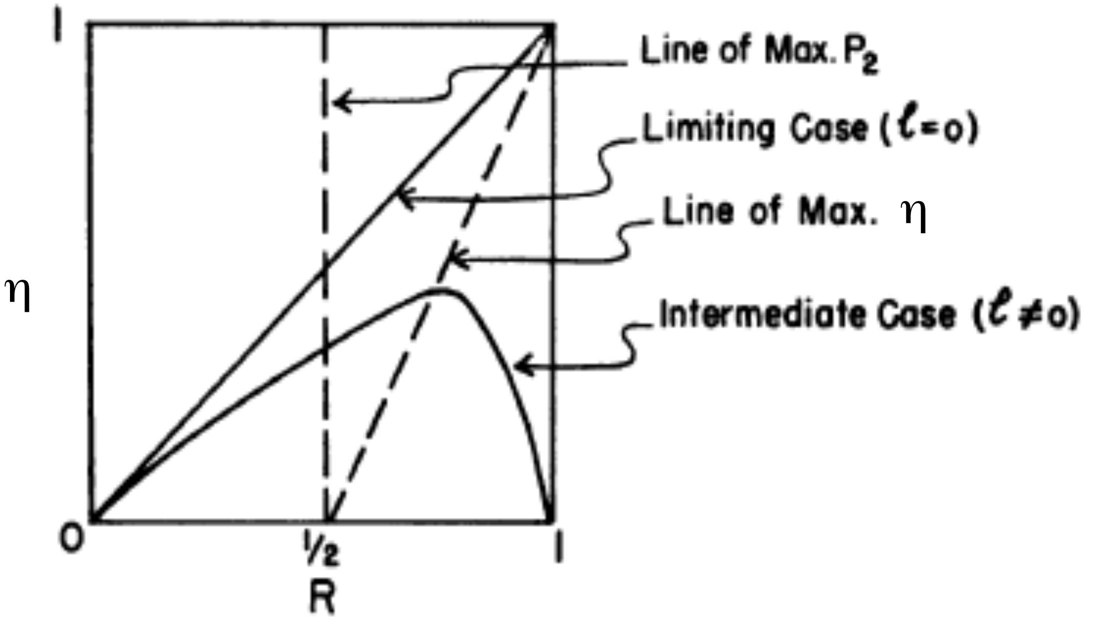

Figure 3. Relationship of efficiency (η) and force ratio (R). A typical curve is drawn for the case where leakage (*f*) is not zero. Values of η for maximum power output are located on the vertical dashed line where R is maximum efficiency, and associated R values are found on the slanting dashed line.

Efficiency optimization for maximum power output rather than efficiency maximization may be suggested as the goal of an economic activity. Surprisingly, this appears the way for successful competition in the global market. Efficiencies lower and efficiencies higher than the optimum efficiency for maximum power output may be a suitable solution respectively in times of abundant resources (now over) and in times of increasing scarcity of resources. An example of the first case was the low efficiency (1%) of the steam Watt machine powering the industrial revolution in the United Kingdom (Figure 4); the second alternative seems to be applicable in the near future, with resources becoming more limiting. Since efficiencies beyond the optimum may entail lower power output, this will force us to consider replacement of competitive with collaborative patterns, where maximum power output does no longer characterize the economies of individual actors but instead the economies of larger networks. Some suggest that this is, for example, the case of circular economy, with resource exchanges and recycling.

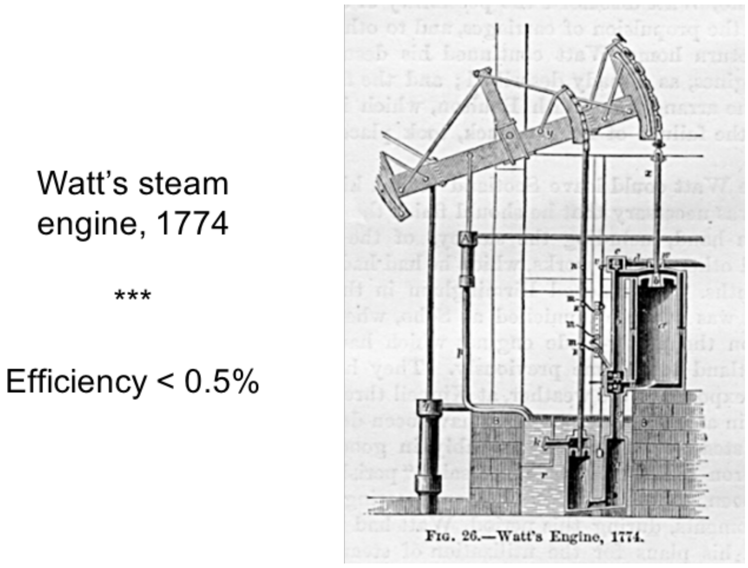

Fig. 4. The low efficiency of the steam Watt engine.

4. A prototype tool for optimization of costs and benefits (i.e. resource use and impacts versus yield)

The goal of the Parthenope team concerning the aspects of "efficiency versus power output", **as highlighted in the previous section**, is therefore to design and partially develop a tool that can be used to make estimates and scenarios. Such a tool might be a valuable contribution to policy making, as far as resource use and impacts of processes are concerned. In fact, energy and resource efficiency aspects as well as minimization of airborne, waterborne and solid emissions are among the most urgent issues in the policy agendas of national EU governments and the EU Commission. The tool we are trying to design allows to identify input and output flows, to attribute them appropriate quality and characterization factors typical of the selected assessment approaches (CMD-Cumulative Material Demand, CED-Cumulative Energy Demand, CEA-Cumulative Emissions Accounting and EMA-EMergy Accounting) and finally to calculate performance indicators of processes and policies at different scales. In a like manner, within a collaboration project with the School of Environment of Beijing Normal University, we are developing an Urban Circular Economy Calculator (UCEC), an online procedure (http://ucec.umsoft.cn/introduce.html) aimed at allowing policy-makers to visualize different scenarios with respect to Water-Energy-Food nexus within the urban context and so address the wicked problem of urban circular economy. The prototype tool was awarded the forth position in the international WEGE prize, organized by US Wege Foundation (http://www.wegeprize.org). An introductory paper about ECEC was submitted to the Biennial International Workshop "Advances in Energy Studies" - BIWAES 2017 and has been included in the Book of Proceedings.

In the presence of alternative choices, it would be possible to quickly compare the environmental costs&benefits associated to each one (e.g. the demand for global environmental support or the global warming potential) and make a first screening among alternatives. After that, the remaining options would of course require a more careful assessment.

It is important to point out that the existing LCA tools only address input and emission flows at the spatial scale of processes (although from cradle to grave), and still leave unaddressed social, economic and resource turnover aspects (i.e. resource generation time within biosphere dynamics), thus disregarding some of the most important cost&benefit factors that should be at the basis of decision making. The prototype calculation procedure we are trying to put forward builds on material flow and impact accounting typical of LCA and moves further ahead to ward a more comprehensive scenario making.

4.1. The structure of the proposed assessment tool

The proposed prototype tool must be endowed with:

a) a user-friendly input page

b) a transparent calculation procedure, including characterization factors, footnotes, references

c) an output page with calculated performance indicators and diagrams.

d) a structure of the calculation procedure that allows sensitivity and/or uncertainty estimates (i.e. the possibility to modify the input data or the characterization factors by a desired percent in order to ascertain how changes on input values affect results). Changes may be due to better data becoming available or may be attributed to uncertainty about the actual value of inputs. This is the core of the calculation procedure, in that it allows to understand to what extent changes in the amount of input flows affect the maximization of the output (in so addressing the alternative "optimization versus maximization".

e) the possibility to add comparisons over time and/or generate standardized comparison with a reference year or a reference system. Without such standardization, expected, planned or achieved improvements cannot be assessed.

f) a sufficient flexibility to allow further integration and comparison with data from other approaches.

In the following the above characteristics are described in details.

4.2 The user-friendly input page

A tool aimed at being used for cost&benefit assessment by policy makers must be characterized by a user-friendly interface, that is self-explanatory and does not require specific informatic expertise nor expensive software. We think of the thousands of potential users at all levels of the administrative chain in all size cities, sectors, productive units, larger community levels. What is proposed in this project is not a highly sophisticated tool, but can be considered a beta-version for further improvement if successful, similar to the Urban Circular Economy Calculator (UCEC), referred to above. The idea is not to create another of the already existing and very valuable specifically designed tools such as LCA commercial software (Simapro or Gaby, to quote some), the use of which requires expert personnel not always available in all Institutions. Instead, the assessment calculator that we are designing aims at a quick understanding of positive and negative consequences of intended actions, as far as resource demand and environmental impacts are concerned.

The introductory page only shows a simple procedure for data input, accompanied by main metadata (definitions, references, units). The same procedure allows to enter an uncertainty range in order to have a quick idea of the consequences of uncertain or incorrect data on final results (sensitivity and uncertainty, see below).

4.3 Transparency in the calculation procedure

What is most often lacking is a procedure to help participatory strategies and discussion on facts that can be understood by non specialist stakeholders. A typical advance in such understanding was given by the introduction of the concepts of "footprint": ecological footprint (demand for productive land), carbon footprint, water footprint, among others, in their basic and more elaborated versions. These concepts, very simple in their design, and other similar sets of indicators, may be used as a basic ground platform for participatory actions and strategies. If policy makers, their collaborators and counterparts (stakeholders, competitors) are able to determine with acceptable reliability the expected or likely consequences of suggested or planned developments (new energy plants, energy saving strategies or tools, replacement of materials, waste management options, local or larger policies) in a simple and quick way that does not require a long time for assessment, then a scientifically sound discussion can be started and involve everybody, based on transparent data and transparent calculation procedures, in a typical "what if" experiment. The proposed tool aims at showing how can this be achieved in a selected number of cases (e.g.: agriculture, energy efficiency and energy saving policies, waste and wastewater treatment, urban systems), in order to make it clear to what extent participatory strategies are possible and suggest the development of easy assessment mechanisms.

4.4 Performance indicators and diagrams.

The outcome of the proposed tool would be a set of absolute and relative indicators strictly linked to input data and uncertainty or sensitivity choices. Absolute data allow to identify the size of each flow or total costs&benefits, while relative indicators allow the identification of crucial steps and aspects, in support of decision making. Indicators will focus on energy flows, matter flows (including water), emissions, demand for ecosystem services (emergy). The "what if" experiments can be performed by first assessing the "state-of-the-art" input and output flows and related performance (efficiency, intensity) indicators and then by forcing the procedure by gradually changing one or more of the input data and the estimated yield. For the sake of clarity, investing resources into some improvement or alternative strategy to raise the performance of a given process step is justified only if it allows a significant improvement, while it would be useless if the expected efficiency increase is small. The tool would allow the immediate comparison of different options (e.g. replacing grid electricity with solar photovoltaic electricity; replacing a natural gas heater with an electric heat pump; using recycled paper instead of virgin paper; and so on), so that a discussion among interested actors would be feasible, based on real data estimates.

4.5 Sensitivity and uncertainty estimates. Optimization versus maximization.

Optimization becomes the crucial issue in participatory strategies. In general, maximization is easier to understand, while optimization requires agreement of criteria (it means everybody must accept a bit less of the expected or the theoretically achievable, in order to generate a global improvement of the performance.). The tool aims at allowing to understand how results are related to inputs and costs and see how a global optimization of the performance (improvement of the largest possible set of performance indicators) can be achieved and the extent of costs.

4.6 Comparison and standardization tools.

Comparison and understanding of achieved and achievable improvements requires benchmark for standardization. Comparison can be drawn against the performance of the same system in previous years, the performance of a reference system considered highly performing, the average performance of a specific spatial scale, the performance of a theoretical system purposefully designed, among others. In general, the concept itself of improvement requires that the proposed change generates better performance than the reference system, while comparing with the absolute perfect solutions (e.g. no emissions at all) seems difficult or impossible and is outside of the goal of the present tool. The tool aims at assessing, let's say, the potential or real achievement of a 3% improvement thanks of a proposed strategy or technical option, compared to the benchmark.

4.7 Integration with other approaches.

The magic bullet, as well known, does not exist. What we have experienced within other projects as well as within the present project EUFORIE - also thanks to the interaction with stakeholders - is that one approach only cannot ensure full understanding of costs and benefits. As a consequence, results from whatever approach must be compared to results from other assessment tools characterized by different assumptions, frameworks and design. Other approaches will be indicated and explored for integration (e.g.: MuSIASEM and others in the present EUFORIE project, Ecological Footprint, Carbon Footprint). The prototype tool we are designing will also clarify constraints, strengths and weaknesses of achieved results and will also indicate their realm of reliability, so that users are informed of what can be expected from it.

The possibility to generate performance indicators that are easily understandable and that change in dependence of the choices to be tested may become a good tool for participatory decision making and conflict prevention. The tool does not aim at replacing policy makers, when it comes the time to make decisions and assume responsibility associated to their role, nor at replacing technical experts, when it comes the time to actually implement the project or the process and many more details are needed. We believe that the successful design and implementation of a user-friendly assessment tool might be part of an online interaction between people in charge for decision making and stakeholders, for conflict prevention and appropriate resource use.

The examples below have already been described, in terms of systems and preliminary results achieved, in the Deliverable D3.1. Here we will only shortly focus on specific aspects of the calculation procedure, related to the prototype tool design.

5. Example No. 1_Agricultural system analysis.

Each system requires a sufficient understanding of its dynamics and characteristics. In the case of an agricultural system, it can be looked at different spatial scales (a farm, a region, the national agricultural level). Some characteristics are common for all levels: identify the amount of cropped land, some environmental characteristics (insolation, rainfall, demand for fertilizers and other chemicals, machinery used for cropping and harvesting and related fuels, electricity for irrigation and related irrigation water, yield depending on the crops and crop rotations, etc). Some aspects related to the data must be clearly explained: which units to be used in each category of input, level of aggregation of data, quality of data. Concerning the output, it must be clearly stated which kind of output are we considering (the yield of a specific crop; the total mass of the crops, specifying if it is dry matter or fresh matter; the energy content of the cropped biomass; the market value in money terms, etc.). In so doing, some kinds of averages and aggregations become possible.

5.1 The structure of the tool

Appendix 1 shows the kind of tentative structure of the calculation procedure that may be implemented in the tool. Table A1 aims at being the user-friendly page, with data and metadata to be entered in the cells highlighted in yellow. The user is requested to enter the real data for the investigated system or to make assumptions based on local averages or experts.

Table A2 shows a typical set of calculation procedures to convert the data entered through the user interface into a standard data format, usable in the final calculation of costs and impacts, according to each individual approach (e.g. converting tons, kg, pounds, etc into grams).

Standardized data from Table A2 are then transferred to Tables A3, A4, A5 where they are converted to Cumulative Material Demand, Cumulative Energy Demand, Cumulative Emissions associated to each input flow and finally Demand for Ecosystem Services (Emergy) in support to the process. In these Tables, data from Table A2 are multiplied by Intensity Factors (IF) and LCA Characterization Factors (CF) that are specific of each method (CMD, CED, CEA, EMA) to convert amounts of flows locally applied to cumulative amounts at larger scale (also including background flows). In so doing, a larger picture is achieved, that goes beyond the actual amounts dealt with locally. The IF and CF are made available within the procedure, but are not shown here.

5.2 Intensity Factors and Characterization Factors

The huge role of Intensity Factors and Characterization Factors within the optimization pattern should not be disregarded. The inventory list of inputs and outputs is not sufficient to fully describe the generation cost (i.e. the supply side quality) of input flows not the contribution of each emission flow to specific Impact Categories. IF and CF allow a comprehensive accounting of the supply-side and user-side characteristics of each flow and allow equivalence assessment among flows as well as comparison and addition. In the optimization procedure, the goal to decrease the absolute value of costs and impacts can only be achieved by preliminarly assigning the right "intensity" and "equivalence" to each flow, in order to make it clear what is its real "size". Only once size is assessed, policies for minimization (absolute decrease) and optimization (decrease potential consistent with resources available and their allocation to each step of the process).

5.3 Indicators

Table A6 (A) starts showing some of the performance indicators of interest, i.e. the calculated ratios of airborne emissions per each Functional Unit at stake, i.e. the emissions associated to one Ha, to one g of dry matter of the main product or residues, to one Euro, to one joule of energy content. These are new efficiency measures, that complement the usual energy efficiency indicators. Table A6 (B) uses characterization factors typical of the Life Cycle Assessment method to convert emissions into equivalents of impacts, for a selection of impact categories, calculated per Functional Unit and globally.

Finally, Table A7.1 to Table A7.5 list a large number of performance indicators based on the above assessment approaches. These results can be easily converted into diagrams, similar to those in Figures A1 to A5, for easier description and understanding.

Of course, the preliminary tool described in this Section and built within an Excel platform needs to be refined and made consistent with requisites listed in Sections 4.2 to 4.7 above. If the system of interest changes, also the input and output items in the user interface change. As a consequence, the user interface will be designed in a flexible way, with more inputs than needed, some of which might be disregarded, or with empty spaces that can be adjusted to the specific need. As an alternative, more than one user interface can be created, for specific sectors, linked to an extensive calculation procedure page that does not need to be changed.

The link between the user interface and the final page of results and diagrams is the main aspect of the proposed tool. In fact, by acting on the user interface it is possible to check how choices affect the final performance.

6. Example No. 2_Urban system analysis. The case of Napoli.

When dealing with systems characterized by a large supporting area, the focus on such area cannot be neglected. Urban systems, in particular, rely on their surrounding area for a variety of services and it is crucial for their administrators to be aware of what is gained and what is lost in case of planned or implemented land use change. Therefore, urban systems require, much more than above agricultural systems, that policy makers and stakeholders focus on the costs and benefits related to surrounding support areas. Here, "costs" may also mean "lost benefits" potentially due to inefficient use of resources. We have published specific results about the urban system of Napoli in the paper Viglia et al. (2017), preliminarly referred to in D3.1. Results were achieved by means of joint use of conventional LCA software and in-house built EMA software running on Excel platform. Main focus was to investigate the costs and impacts of the local as well as supply-chain processes and to ascertain how land-related environmental services to dilute and buffer these impacts are linked to appropriate and efficient resource use. The assessment tool described above in Section 5 was enriched by means of a specific land-use related procedure, to calculate the land-footprint of the urban system, depending on a variety of assumptions.

The difference between our calculation procedure and the conventional Ecological Footprint procedure mainly relies on the use of IFs and CFs described above, which assign to each input and output flow a size and a meaning much beyond the simple assessment of their mass.

Figure 5 is a simplified energy system diagram showing the aggregated flows (R for renewables, N for local non-renewables, F for imported resources, and LS_N and LS_R for the non-renewable and the renewable fraction of labor and services), all supporting the life of a city. A key for symbols is provided in the above referred D3.1. While all these flows are directly and indirectly related to the source function of Nature, the flow R_1 in the diagram represent the ecosystem services associated to the sink function. As supporting flows are not only from the local region, also the additional emergy required to dilute the downstream environmental impacts generated by the city cannot be only available locally, but also operates at larger scales. Calculation of emissions all over the supply chain was made possible by the use of LCA software.

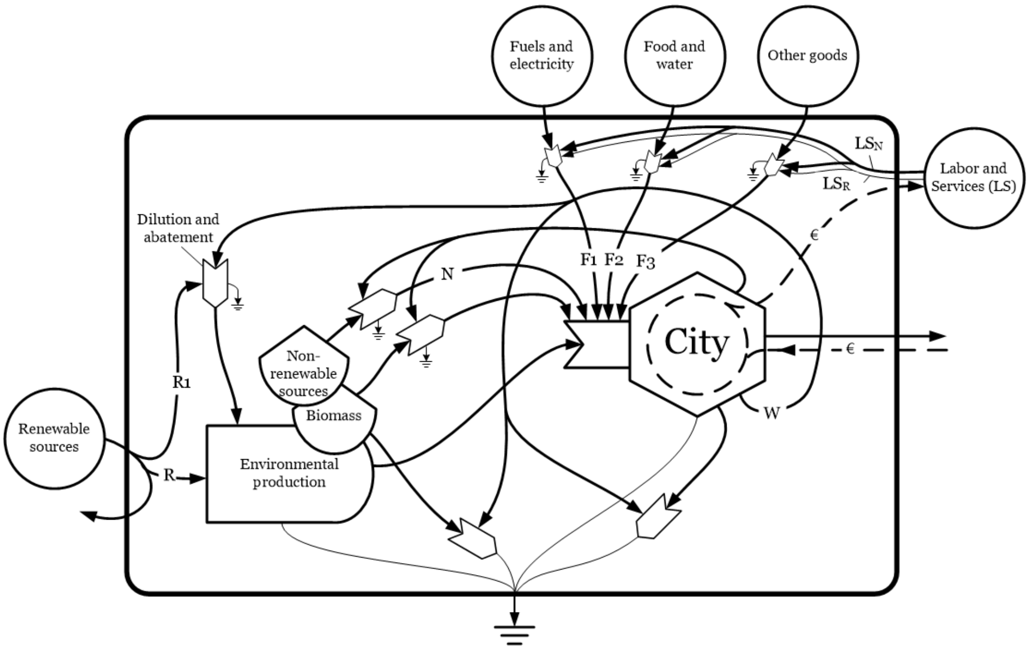

Figure 5. Simplified energy system diagram of a city (R for renewables, R_1 for additional emergy required to dilute the downstream environmental impacts of the city, N for local non-renewables, F_1 for imported energy, F_2

for imported food and water, F_3 for other goods, LS_N and LS_R for the non-renewable and the renewable fraction of labor and services respectively, W for downstream environmental impacts.

In a like manner as with the previous example (Section 5), several criteria can be adopted and applied:

6.1 *A performance-oriented approach: calculation of indicators based on resource use*

A set of indices and ratios suitable for policymaking can be calculated:

* Total emergy, $U = R + N + F + LS_R$ and LS_N. It measures the convergence of renewable (R), nonrenewable (N) and imported (F, LS_R and LS_N) emergy to support the city.

* Emergy intensity of Functional Units referred to:

- Population emergy intensity = U/inhabitants. It measures how much emergy it takes to support one average person, regardless of whether the input is renewable or not.
- Currency emergy intensity = U/GDP. It measures how much emergy it takes to generate an average unit of money in a given year.

* Emergy yield ratio, $EYR = (R + N + F + LS_R + LS_N)/(F + LS_R + LS_N)$. It is a measure of the ability of a process to exploit and make available locally renewable (R) and nonrenewable (N) resources by investing outside resources (F and LS). It is an index sensitive to the alternative local-imported and it is of crucial importance for an urban system.

* Environmental loading ratio, $ELR = (N + F + LS_N)/(R + LS_R)$. It compares the amount of nonrenewable (N) and imported (F and LS_N) emergy to the amount of locally renewable emergy sources ($R+LS_R$). In a way, the ELR is a measure of the possible disturbance to the environmental dynamics, generated by the local development driven from outside sources. The ELR is clearly able to make a difference between nonrenewable and renewable resources, thus complementing the information that is provided by the emergy intensities.

* Renewable Fraction of emergy use, %REN = R/U, the fraction of emergy that is from local or imported renewable sources.

* Emergy Sustainability Index, ESI = EYR/ELR. It is an aggregated indicator of sustainability that links the characteristics of the EYR (sensitive to the outside-versus-local emergy alternative) and the ELR (sensitive to the nonrenewable-versus-renewable emergy alternative). It responds to the goal of relying on the largest possible amount of local resources in a process at the lowest possible environmental loading locally and elsewhere.

6.2 A downstream-oriented approach: The LCA-emergy cost of emission dilution and waste treatment

The calculation tools focuses on airborne, liquid and solid emissions generated by the system and calculates the supporting area needed for their dilution and abatement by surrounding land-related ecosystem services, at local and supply-chain scales, with and without additional collection and abatement technologies. The procedure allows the quantification of the mass of air or water needed for the dilution of the emissions to the desired concentration (legally imposed or environmental background oriented). This “control mass” is assumed to cross the area where the emissions are released and spread them through a larger area at lower concentration.

The quantification of emissions is performed via LCA software while environmental services are calculated based on the kinetic energy of the wind or current in the water body, to be in turn used to compute the emergy flow supporting the dilution process. It is worth noting that linking the environmental service to a dilution process translates into a simplified model of the interaction of the emission source and the environment, affected by a large uncertainty about the way emissions are actually uptaken, diluted or abated via the complex sequence of chemical reactions within atmosphere, water bodies and soil. However, the “control mass” model, although likely under-estimating the amount of environmental services actually needed, at least provides a reference value for comparison of different systems and potential improvements in their resource use.

Further details are provided in the D3.1 and Viglia et al. (2017). Results translate into the need to set aside a buffer land (green areas within or around the city) or to optimize the process in order to minimize input and output flows. Table 1 compares such results for a selection of urban systems of different size.

Table 1. Calculated additional area (m^2) needed to provide the ecosystem services (emergy) needed to dilute local and global emissions according to Italian regulation (Environmental law n. 152, 2006) and down to the natural background condition.

		Roma	Napoli	Vico Equense	Massa Lubrense	Ischia
Actual Area (AA)	m^2	1.29E+09	1.17E+08	2.93E+07	1.97E+07	8.05E+06
Dilution of local and global emissions according to legally enforced concentration						
$LCDA_1$	m^2	1.20E+09	1.55E+08	4.96E+05	2.66E+05	6.63E+05
$LCAF_1$	$LCDA_1/AA$	**0.93**	**1.32**	**0.017**	**0.014**	**0.082**
$LCDA_2$	m^2	3.39E+09	1.05E+09	1.06E+06	3.57E+05	4.64E+06
$LCAF_2$	$LCDA_2/AA$	**2.64**	**8.98**	**0.04**	**0.02**	**0.58**
Dilution of local and global emissions down to background environmental concentration						
$BCDA_1$	m^2	1.11E+11	1.44E+10	4.61E+07	2.47E+07	6.16E+07
$BCAF_1$	$BCDA_1/AA$	**86.67**	**122.78**	**1.57**	**1.25**	**7.65**
$BCDA_2$	m^2	2.38E+11	4.86E+10	9.87E+07	3.31E+07	1.89E+08
$BCAF_2$	$BCDA_2/AA$	**185.17**	**414.67**	**3.37**	**1.68**	**23.43**

Notes: LCDA (Legal Concentration Dilution Area) and BCDA (Background Concentration Dilution Area). The "legal" and "background" areas are calculated with reference to both emissions released on local scale ($LCDA_1$ and $BCDA_1$, mainly from local combustion of fuels), and emissions released on a global scale ($LCDA_2$ and $BCDA_2$, also including emissions over the supply-chain of imported energy and materials). Further, the ratios between these calculated dilution areas and the actual city areas provide a measure of the distance of each urban system from the selected dilution target, through the definition of land amplification factors depending on the desired dilution: *Legal Concentration Amplification Factors* ($LCAF_1$ and $LCAF_2$) and *Background Concentration Amplification Factors* ($BCAF_1$ and $BCAF_2$).

Since CO2 is not included in the above pollutant dilution calculation (CO2 impacts are not decreased by dilution but only by photosynthetic uptake), a similar calculation can be performed in terms of area set aside for forestry (Endreny et al., 2107). Results from Table 2 are in the same order of magnitude as results from Table 1, which confirms the absolute need for reduction of emissions and, at the same time, setting aside enough buffer area for sustainable city development.

Table 2. Areas needed for uptake of local and global scale CO_2 emissions considering the mean value of NPP (400 g/m^2 of Carbon absorbed in one year) in the Mediterranean region (after Lieth, 1975).

	Roma	Napoli	Vico Equense	Massa Lubrense	Ischia
CO_2 emissions at local scale (g/yr)	1.31E+13	1.01E+12	1.65E+09	1.95E+09	4.05E+09
Area to uptake local CO_2 emissions (m^2)	8.93E+09	6.85E+08	1.12E+06	1.33E+06	2.76E+06
CO_2 AF	**6.95**	**5.84**	**0.04**	**0.07**	**0.34**
CO_2 emissions at global scale (g/yr)	5.07E+13	7.63E+12	5.65E+09	4.81E+09	1.78E+10
Area to uptake global CO_2 emissions (m2)	3.46E+10	5.20E+09	3.85E+06	3.28E+06	1.21E+07
CO_2 AF	**26.89**	**44.34**	**0.13**	**0.17**	**1.50**

6.3 An upstream-oriented approach: An upstream-oriented approach: Calculating emergy-related support areas based on sustainability assumptions

The virtual area DA for emission dilution constitutes, as already mentioned, a downstream-oriented environmental support to a process, in that it is linked to the amount of emissions released. However, processes cannot occur if upstream resource flows are not made available. Within the emergy approach framework, a mix of locally renewable (R) and nonrenewable (N) as well as imported from outside (F) resources is needed for a process to occur. These resources are generated by the present ecosystem activity (the flow R) as well as by the past dynamics that created resource storages (natural capital, such as oil, mineral reservoirs, standing forests). By imposing the condition that the investigated system fulfils specific sustainability requirements at local or global scale (mainly generates a lower emergy loading ELR or is characterized by a higher sustainability indicator ESI, than the reference national or world average system), results described in Table 3 are obtained.

Table 3. Emergy-based indicators measuring the set aside area (m^2) needed to generate ecosystem services in support of the desired level of sustainability.

		Roma	Napoli	Vico Equense	Massa Lubrense	Ischia
Actual Area (AA)	m^2	1.29E+09	1.17E+08	2.93E+07	1.97E+07	8.05E+06
Assumption 1: fully renewable support to the system (Equation 7)						
TRA	m^2	1.72E+12	4.46E+10	3.80E+09	4.90E+08	1.28E+09
TRAF	TRA/AA	**1338**	**380**	**130**	**25**	**159**
Assumption 2: $ELR_{system} \leq ELR_{country}$ (Equation 9)						
RLA	m^2	7.03E+10	1.82E+09	1.55E+08	2.00E+07	5.23E+07
RLAF	RLA/AA	**54.7**	**15.5**	**5.3**	**1.02**	**6.5**
Assumption 3: $ESI_{system} \geq ESI_{country}$ (Equation 10)						
RSA	m^2	6.56E+10	1.42E+09	1.39E+08	1.82E+07	3.85E+07
RSAF	RSA/AA	**51.0**	**12.1**	**4.8**	**0.925**	**4.8**
Assumption 4: ESI_{system} = 10 (selected as worldwide reference value, Equation 11)						
ASA	m^2	1.72E+13	4.43E+11	3.76E+10	4.69E+09	1.27E+10
ASAF	ASA/AA	**13346**	**3781**	**1284**	**238**	**1575**

Notes:

TRA= Total Renewability Area; TRAF= Total Renewability Amplification Factor

RLA= Relative Loading Area; RLAF= Relative Loading Amplification Factor

RSA= Relative Sustainability Area; RSAF= Relative Sustainability Amplification Factor

ASA= Absolute Sustainability Area; ASAF= Absolute Sustainability Amplification Factor.

Once again, after a set of indicators are calculated and their variability assessed depending on choices, resource use efficiency, use assumptions, resource quality assumptions, uncertainty and quality of data, police debate is made easier or, at least, misunderstandings and insufficient information are prevented. If the tool is refined, made user-friendly according to the above criteria (Section 4), and made available online, scenarios and performance indicators can be assessed and discussion is about facts and perspectives, not about rumors and false perceptions.

7. Conclusions

A prototype tool is in progress for policy use to assess the energy and resource use efficiency, as well as environmental costs and benefits of development choices, to serve as a preliminary assessment for policy making and stakeholders involvement within participatory processes. If proved effective, the tool would be a first aid to prevent conflicts and facilitate dialogue.

This task within the EUFORIE project WP 3 aims at designing the main characteristics and providing examples of actual application of a prototype version, in order to prove the feasibility and usefulness of such a tool within a resource efficiency perspective.

The present state of the activity is the design and testing of specific cases. The most difficult part of the procedure will be to design something that is flexible enough to be applicable to different case studies and goals, without requiring specific expertise in modelling and software. Of course, once the main characteristics of the tool are designed and tested, the final implementation of a usable tool may require software expertise (graphic interface, libraries, etc) and a purposefully funded project.

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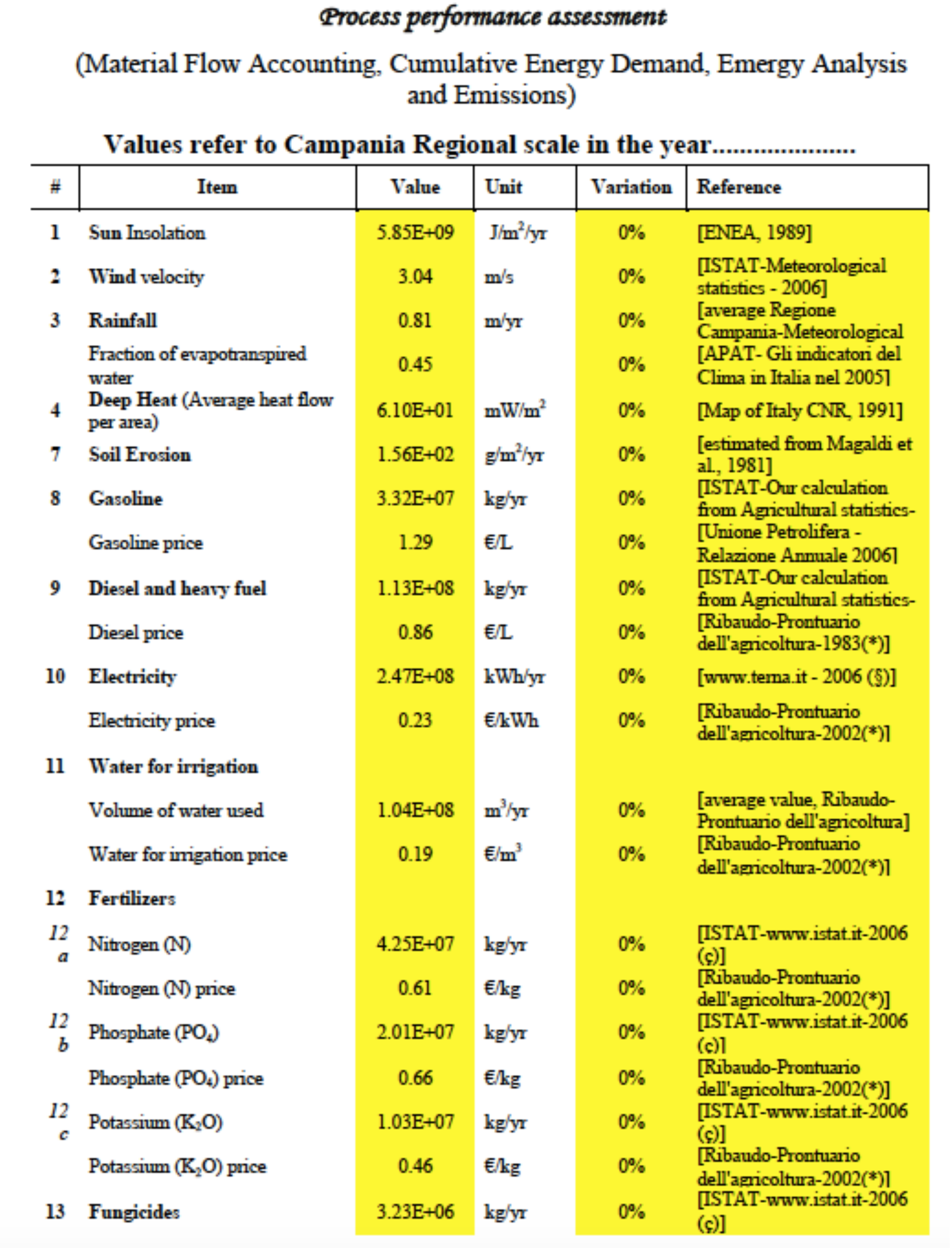
APPENDIX

Table A1 - User Interface for data entry (references indicated in the Appendix are not added to the Bibliography)

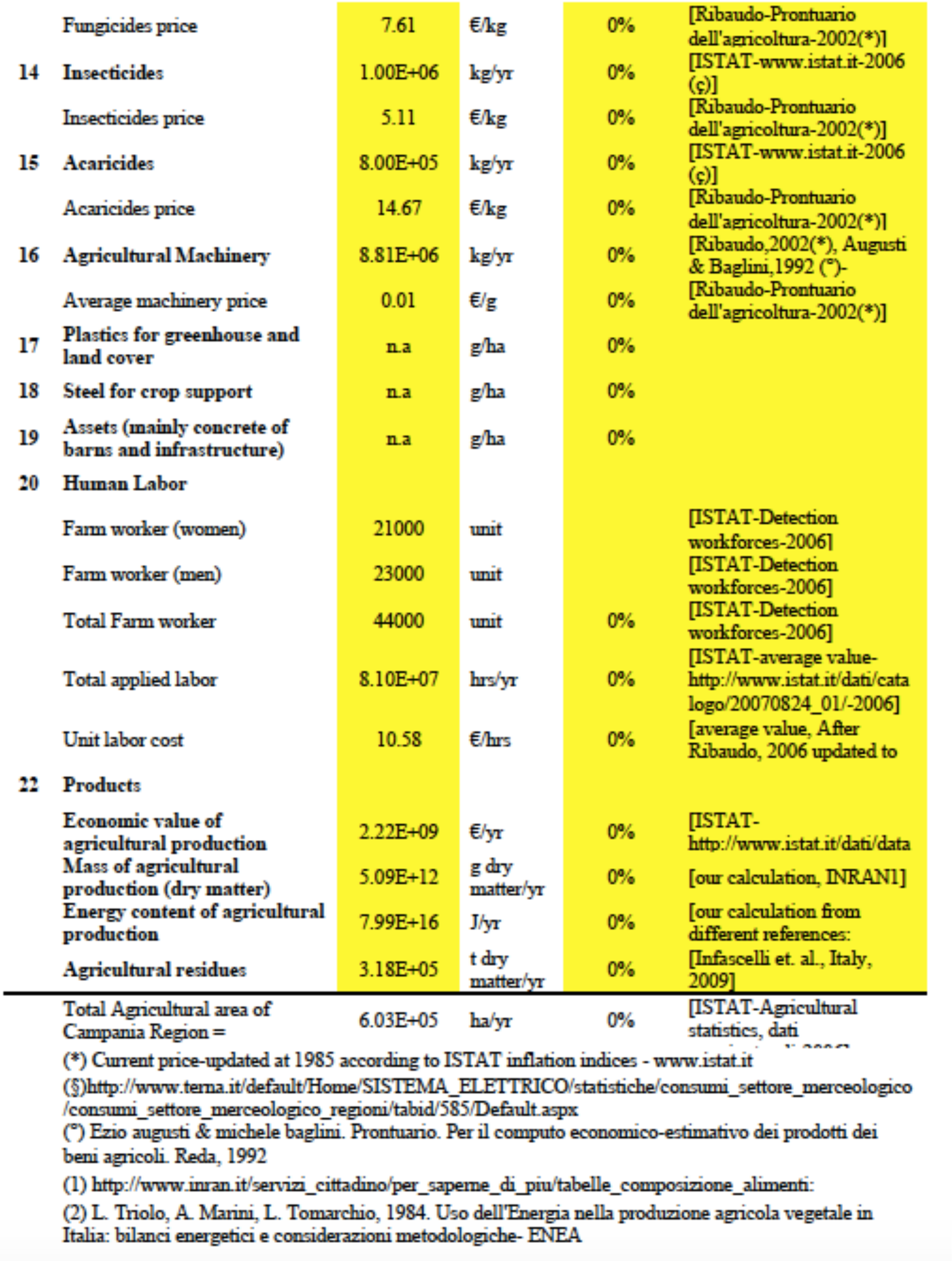


Process performance assessment

(Material Flow Accounting, Cumulative Energy Demand, Emergy Analysis and Emissions)

Values refer to Campania Regional scale in the year....................

#	Item	Value	Unit	Variation	Reference
1	**Sun Insolation**	5.85E+09	$J/m^2/yr$	0%	[ENEA, 1989]
2	**Wind velocity**	3.04	m/s	0%	[ISTAT-Meteorological statistics - 2006]
3	**Rainfall**	0.81	m/yr	0%	[average Regione Campania-Meteorological
	Fraction of evapotranspired water	0.45		0%	[APAT- Gli indicatori del Clima in Italia nel 2005]
4	**Deep Heat** (Average heat flow per area)	6.10E+01	mW/m^2	0%	[Map of Italy CNR, 1991]
7	**Soil Erosion**	1.56E+02	$g/m^2/yr$	0%	[estimated from Magaldi et al., 1981]
8	**Gasoline**	3.32E+07	kg/yr	0%	[ISTAT-Our calculation from Agricultural statistics-
	Gasoline price	1.29	€/L	0%	[Unione Petrolifera - Relazione Annuale 2006]
9	**Diesel and heavy fuel**	1.13E+08	kg/yr	0%	[ISTAT-Our calculation from Agricultural statistics-
	Diesel price	0.86	€/L	0%	[Ribaudo-Prontuario dell'agricoltura-1983(*)]
10	**Electricity**	2.47E+08	kWh/yr	0%	[www.tema.it - 2006 (§)]
	Electricity price	0.23	€/kWh	0%	[Ribaudo-Prontuario dell'agricoltura-2002(*)]
11	**Water for irrigation**				
	Volume of water used	1.04E+08	m^3/yr	0%	[average value, Ribaudo-Prontuario dell'agricoltura]
	Water for irrigation price	0.19	$€/m^3$	0%	[Ribaudo-Prontuario dell'agricoltura-2002(*)]
12	**Fertilizers**				
12 a	Nitrogen (N)	4.25E+07	kg/yr	0%	[ISTAT-www.istat.it-2006 (ç)]
	Nitrogen (N) price	0.61	€/kg	0%	[Ribaudo-Prontuario dell'agricoltura-2002(*)]
12 b	Phosphate (PO_4)	2.01E+07	kg/yr	0%	[ISTAT-www.istat.it-2006 (ç)]
	Phosphate (PO_4) price	0.66	€/kg	0%	[Ribaudo-Prontuario dell'agricoltura-2002(*)]
12 c	Potassium (K_2O)	1.03E+07	kg/yr	0%	[ISTAT-www.istat.it-2006 (ç)]
	Potassium (K_2O) price	0.46	€/kg	0%	[Ribaudo-Prontuario dell'agricoltura-2002(*)]
13	**Fungicides**	3.23E+06	kg/yr	0%	[ISTAT-www.istat.it-2006 (ç)]



	Fungicides price	7.61	€/kg	0%	[Ribaudo-Prontuario dell'agricoltura-2002(*)]
14	**Insecticides**	1.00E+06	kg/yr	0%	[ISTAT-www.istat.it-2006 (ç)]
	Insecticides price	5.11	€/kg	0%	[Ribaudo-Prontuario dell'agricoltura-2002(*)]
15	**Acaricides**	8.00E+05	kg/yr	0%	[ISTAT-www.istat.it-2006 (ç)]
	Acaricides price	14.67	€/kg	0%	[Ribaudo-Prontuario dell'agricoltura-2002(*)]
16	**Agricultural Machinery**	8.81E+06	kg/yr	0%	[Ribaudo,2002(*), Augusti & Baglini,1992 (°)-
	Average machinery price	0.01	€/g	0%	[Ribaudo-Prontuario dell'agricoltura-2002(*)]
17	**Plastics for greenhouse and land cover**	n.a	g/ha	0%	
18	**Steel for crop support**	n.a	g/ha	0%	
19	**Assets (mainly concrete of barns and infrastructure)**	n.a	g/ha	0%	
20	**Human Labor**				
	Farm worker (women)	21000	unit		[ISTAT-Detection workforces-2006]
	Farm worker (men)	23000	unit		[ISTAT-Detection workforces-2006]
	Total Farm worker	44000	unit	0%	[ISTAT-Detection workforces-2006]
	Total applied labor	8.10E+07	hrs/yr	0%	[ISTAT-average value-http://www.istat.it/dati/catalogo/20070824_01/-2006]
	Unit labor cost	10.58	€/hrs	0%	[average value, After Ribaudo, 2006 updated to
22	**Products**				
	Economic value of agricultural production	2.22E+09	€/yr	0%	[ISTAT-http://www.istat.it/dati/data
	Mass of agricultural production (dry matter)	5.09E+12	g dry matter/yr	0%	[our calculation, INRAN1]
	Energy content of agricultural production	7.99E+16	J/yr	0%	[our calculation from different references:
	Agricultural residues	3.18E+05	t dry matter/yr	0%	[Infascelli et. al., Italy, 2009]
	Total Agricultural area of Campania Region =	6.03E+05	ha/yr	0%	[ISTAT-Agricultural statistics, dati

(*) Current price-updated at 1985 according to ISTAT inflation indices - www.istat.it

(§)http://www.terna.it/default/Home/SISTEMA_ELETTRICO/statistiche/consumi_settore_merceologico/consumi_settore_merceologico_regioni/tabid/585/Default.aspx

(°) Ezio augusti & michele baglini. Prontuario. Per il computo economico-estimativo dei prodotti dei beni agricoli. Reda, 1992

(1) http://www.inran.it/servizi_cittadino/per_saperne_di_piu/tabelle_composizione_alimenti:

(2) L. Triolo, A. Marini, L. Tomarchio, 1984. Uso dell'Energia nella produzione agricola vegetale in Italia: bilanci energetici e considerazioni metodologiche- ENEA

Table A2 - CALCULATION PROCEDURES

	N.B. all data refer to agricultural land in Region Total Agricultural area of Campania Region =	6.03E+05	ha/yr	6.03E+09	m^2	[ISTAT-Agricultural statistics, dati congiunturali-2006]
	Renewable Input (locally available)					
1	**Sun Insolation**					
	Solar energy received = (avg. Insolation, J/m2/yr)(area, m2)=	3.52E+19	J/yr			
	Albedo	0.20				
	Solar energy received =			2.82E+19	J/yr	
2	**Wind**					
	Wind energy = (air density, kg/m^3)(drag coeff.)(geostrophic wind velocity, m/s)^3(area, m^2)(sec/year)=					
	Air density =	1.3	kg/m3			
	Wind velocity (average 2005) =	3.04	m/s			[ISTAT-Meteorological statistics - 2006]
	Geostrophic wind =	5.2	m/s			
	Drag coeff. =	3.00E-03				
	Time frame =	3.15E+07				
	Wind energy on land =			1.04E+17	J/yr	
3	**Rainfall**					
	Rain (average temperate areas) =	0.81	m/yr			[average Campania Region - Meteorological data - 2006 (°)]
	Water density	1.00E+06	g/m^3			
	Mass of rainfall water =	4.88E+15	g/yr			
	Fraction of water that is evapotranspired	0.45				[APAT- Gli indicatori del Clima in Italia nel 2005]
	Evapotranspired rain water	0.36	m/yr			
	Mass of evapotranspired water	2.20E+15	g/yr			
	Free energy of water=(evapotranspired water, g/ha/yr)(Gibbs free energy per gram of water, J/g)=					
	Gibbs free energy of water	4.94	J/g			[Odum, 1996]
	Energy of evapotranspired rain water			1.09E+16	J/yr	
4	**Deep Heat (Average heat flow per area)**					
	Heat flow through earth crust contributing to uplift replacing erosion.					
	Average heat flow per area =	6.10E+01	mW/m2			[Map of Italy CNR, 1991]
	=	1.92E+06	J/m^2/yr			
	Energy (J/yr) = (land area, m^2)(heat flow per area, J/m2/yr)=			1.16E+16	J/yr	

5 Free Air Components for Combustion Processes

5a *O2 for combustion of fuels and oxidation of topsoil:*

Fuels (approximate raw formula assumed to be nCH1.5 for diesel and gasoline, CH0.8 for coal, and CH4 for methane) react with oxygen to yield CO2, H2O vapours, and other combustion gases. Emissions from each fuel combustion are estimated below in the footnotes. In addition, some oxygen is required for topsoil oxidation process (see footnote for topsoil, below)

The following is a summary of estimated oxygen demand in the agricultural step:

Oxygen for topsoil oxidation	2.15E+10	g O2
Total oxygen demand	2.15E+10	g O2

5b *Nitrogen in air inflow*

O2 in air is always coupled to N2 and Ar in a proportion 21%-78%-1% mol/mol. Pumping in oxygen from air requires that N2, Ar, etc. are also supplied to the combustion process.

The following is a summary of estimated nitrogen demand in the agricultural step:

5c *Ar in air inflow*

The following is a summary of estimated Ar flows involved:

6 Photosynthesis related inputs (CO2 and H2O)

Roughly assuming biomass has a average raw formula nC6H12O6. Photosynthetic reaction is:

6CO2 + 6H2O = C6H12O6 + 6O2

6 * (44 g CO2) + 6 * (18 g H2O) = 180 g biomass + 6 * (32 g O2)

256 g CO2 + 108 g H2O = 180 g biomass + 192 g O2

Therefore, producing 1 gram of dry biomass requires :

CO2 demand per g dry biomass produced	1.42	g CO2/ g dry biomass
H2O demand per g dry biomass produced	0.60	g H2O/g dry biomass

CO2 used for photosynthesis (product)	7.24E+12	g CO2/yr
CO2 used for photosynthesis (residues)	4.53E+05	g CO2/yr
Total CO2 used for photosynthesis	7.24E+12	g CO2/yr

H2O used for photosynthesis (product)	3.05E+12	g H2O/yr
H2O used for photosynthesis (residues)	1.91E+05	g H2O/yr
Total H2O used for photosynthesis	3.05E+12	g H2O/yr

Nonrenewable Input (locally available)

7 Net Loss of Organic Matter in Topsoil

Erosion rate	1.56E+02	g/m2/yr		[estimated from Magaldi et al., 1981]
Net loss of topsoil = (farmed area, m2)(erosion rate, g/m2/yr) =		9.40E+11	g/yr	

Organic matter in soil is reported in the range 3-6% of total soil weigh in Italy (estimated from Medici and Martinelli 1963, Magaldi et al. 1981 and Riffaldi et al. 1994).
Other estimates report average values in the range 3 to 5 % (OTA, 1993; Follet et al., 1987; Odum, 1996) for U.S. soils. We will therefore use an intermediate figure within these ranges.

Average % organic in soil (w.m.)=	0.03			[http://eusoils.jrc.ec.europa.eu/ - 2010]
Organic matter in topsoil used up=				
=(total mass of topsoil)(% organic)=		2.82E+10	g/yr (w.m.)	
Water content in organic matter	0.30			[Verrastro, 2009 - personal comunication average value]
Dry organic matter lost with erosion	1.97E+10	g/yr d.m.		
Energy content of dry organic matter	5.00	kcal/g d.m.		(average value for dry organic matter)
Energy loss= (loss of dry organic matter)(5 kcal/g)(4186 J/kcal) =		4.13E+14	J/yr	

Imported Input

8 Gasoline

Gasoline =	3.32E+07	kg/yr		[ISTAT-Our calculation from Agricultural statistics-2006]
=		3.32E+10	g/yr	
HHV =	4.67E+01	MJ/kg =		[Ulf Bossel European Fuel Cell Forum, 2003]
	4.67E+04	J/g		
Gasoline energy =		1.55E+15	J/yr	
Gasoline price =	1.29E+00	€/L		[Unione Petrolifera - Relazione Annuale 2006]

	Gasoline density =	7.53E+02	kg/m^3 =			[http://www.combustibile.it/benzina.html]
		7.50E+02	g/L			
	Total gasoline cost =			5.72E+07	€/yr	
9	**Diesel and heavy fuel**					
	Diesel =	1.13E+08	kg/yr			[ISTAT-Our calculation from Agricultural statistics-2006]
	=			1.13E+11	g/yr	
	HHV =	4.59E+01	MJ/kg =			[Ribaudo-Prontuario dell'agricoltura-1983(*)]
		4.59E+04	J/g			
	Diesel energy =			5.19E+15	J/yr	
	Diesel price =	8.64E-01	€/L			[Ribaudo-Prontuario dell'agricoltura-1983(*)]
	Diesel density =	8.21E+02	kg/m^3 =			[http://www.combustibile.it/gasolio.html]
		8.33E+02	g/L			
	Diesel cost =			1.17E+08	€/yr	
10	**Electricity**					
	Electricity =	2.47E+08	kWh/yr			[www.terna.it - 2006 (§)]
	=			8.87E+14	J/yr	
	Price =	0.230328	€/kWh			[Ribaudo-Prontuario dell'agricoltura-2002(*)]
	Electricity cost =			5.68E+07	€/yr	
11	**Water for irrigation**					
	Volume of water used =	1.04E+08	m3/yr			[average value, Ribaudo-Prontuario dell'agricoltura]
	Water density =	1	kg/L =			
	=	1.00E+03	kg/m3 =			
	=	1.00E+06	g/m^3			
	Mass water =			1.04E+14	g/yr	
	Price =	0.19	€/m3			[Ribaudo-Prontuario dell'agricoltura-2002(*)]
	Water for irrigation cost=			1.98E+07	€/yr	
	Fraction of irrigation water that is evapotranspired	0.45				[APAT- Gli indicatori del Clima in Italia nel 2005]
	Evapotranspired irrigation water	4.68E+13	g/yr			
	Gibbs free energy of water	4.94	J/g			[Odum, 1996]
	Free energy of water=					
	(irrigation evapotraspired water, g/ha/yr)(Gibbs free energy, J/g)=			2.31E+14	J/yr	
12	**Fertilizers**					
12a	Nitrogen (N)	4.25E+07	kg/yr			[ISTAT-www.istat.it-2006 (ç)]
	=			4.25E+10	g/yr	
	Price =	6.10E-01	€/kg			[Ribaudo-Prontuario dell'agricoltura-2002(*)]
	Nitrogen (N) cost =			2.59E+07	€/yr	
12b	Phosphate (PO4)	2.01E+07	kg/yr			[ISTAT-www.istat.it-2006 (ç)]

	=		2.01E+10	g/yr	
	Price =	6.60E-01	€/kg		[Ribaudo-Prontuario dell'agricoltura-2002(*)]
	Phosphorus (PO4) cost =		1.33E+07	€/yr	
12c	Potassium (K2O)	1.03E+07	kg/yr		[ISTAT-www.istat.it-2006 (ç)]
	=		1.03E+10	g/yr	
	Price =	4.60E-01	€/kg		[Ribaudo-Prontuario dell'agricoltura-2002(*)]
	Potassium (K2O) cost =		4.74E+06	€/yr	
13	**Fungicides**				
	Fungicides	3.23E+06	kg/yr		[ISTAT-www.istat.it-2006 (ç)]
	=		3.23E+09	g/yr	
	Fungicides price	7.61E+00	€/kg		[Ribaudo-Prontuario dell'agricoltura-2002(*)]
	Fungicide cost =		2.46E+07	€/yr	
14	**Insecticides**				
	Mass of insecticides used=	1.00E+06	kg/yr		[ISTAT-www.istat.it-2006 (ç)]
	=		1.00E+09	g/yr	
	Price =	5.11E+00	€/kg		[Ribaudo-Prontuario dell'agricoltura-2002(*)]
	Insecticides cost =		5.13E+06	€/yr	
15	**Acaricides**				
	Mass of acaricides used=	8.00E+05	kg/yr		[ISTAT-www.istat.it-2006 (ç)]
	=		8.00E+08	g/yr	
	Price =	1.47E+01	€/kg		
	Acaricides cost=		1.17E+07	€/yr	
16	**Agricultural Machinery**				
	Machinery Mass	8.81E+06	kg/yr		[Ribaudo,2002(*), Augusti & Baglini,1992 (°)-http://www.agroengine.com/]
		8.81E+09	g		
	Mass allocated to one year		8.81E+09	g/yr	
	fraction of steel and iron	0.82	7.22E+09	g/yr	[after Jarach,1985]
	fraction of alluminum	0.14	1.23E+09	g/yr	[after Jarach,1985]
	fraction of rubber and plastic material	0.01	8.81E+07	g/yr	[after Jarach,1985]
	fraction of copper	0.03	2.64E+08	g/yr	[after Jarach,1985]
	Average machinery price	0.010	€/g		[Ribaudo-Prontuario dell'agricoltura-2002(*)]
			8.81E+07	€/yr	
17	**Plastics for greenhouse and land cover**	n.a			
18	**Steel for crop support**	n.a			

19	**Assets (mainly concrete of barns and infrastructure)**		n.a		
20	**Human Labor**				
	Farm worker (women)		21000	unit	
	Farm worker (men)		23000	unit	
	Total Farm worker		44000	unit	
	Total applied labor=		8.10E+07	hrs/yr	[ISTAT-average value- http://www.istat.it/dati/catalogo/20070824_01/-2006]
		=	1.84E+03	hrs/yr/farm worker	
		=	35.40	hrs/week/farm worker	
		=	7.08	working years (5 work days/wee)	
	Unit labor cost		10.58	€/hrs	[average value, After Ribaudo, 2006 updated to inflation]
	Total cost of labor			8.57E+08 €/yr	
21	**Annual Services in Agricultural Production**				
	Total services measured by economic cost of inputs			4.24E+08 €/yr	
22	**Products**				
	Economic value of agricultural production		2.22E+09	€/yr	[ISTAT- http://www.istat.it/dati/dataset/20070601_00/-2006]
	Mass of agricultural production (dry matter)		5.09E+12	g dry matter/yr	[our calculation, INRAN1]
	Energy content of agricultural production		7.99E+16	J/yr	[our calculation from different references: INRAN1 and ENEA2]
	Agricultural residues		3.18E+05	t dry matter/yr	[Infascelli et. al., Italy, 2009]
				3.18E+11 g dry matter/yr	
23	**O2 Released from Photosynthetic reactions**				
	See above calculations about photosynthesis.				
	O2 release per gram dry biomass produced		1.07E+00	g O2/g dry biomass	
	Total O2 released from photosynthesis		5.77E+12	g	
24	**Evapotranspiration (Evaporation from soil + Water transpired by the crop)**				
	Evapotranspiration for 1 ha of the agricultural estimated from average data for Italy (ISTAT, 1993).				
	Fraction of evapotranspired water		0.45		[ISTAT,1993]
	Total mass of evapotranspired water		2.24E+15	g/yr	
25	**CO_2 Output from topsoil oxidation**				

Oxidation of organic matter releases about 1.5 g CO2 per g dry organic.
Therefore, 1 g soil eroded releases
(1-0.70)(0.03 g organic matter per g soil)(1.5 g CO2/g organic matter)=

=	3.15E-02	g CO2/g soil eroded	
CO2 from topsoil oxidation	2.96E+10	g CO2/ha	
Water released	8.46E+09	g water/ha	
O2 required in the oxidation process	2.29E-02	g O2 /g soil eroded	
O2 in the oxidation process, totalling	2.15E+10	g O2	

26 Waste heat from agricultural phase

Sum of heat released by all processes	7.63E+15	J/yr	

27 Water runoff from rain and rrigation

Water content of crops	20%		[CNR-PFMA, 1981, p.5]
Water content of residues	40%		[CNR-PFMA, 1981, p.5]

Runoff is calculated as:

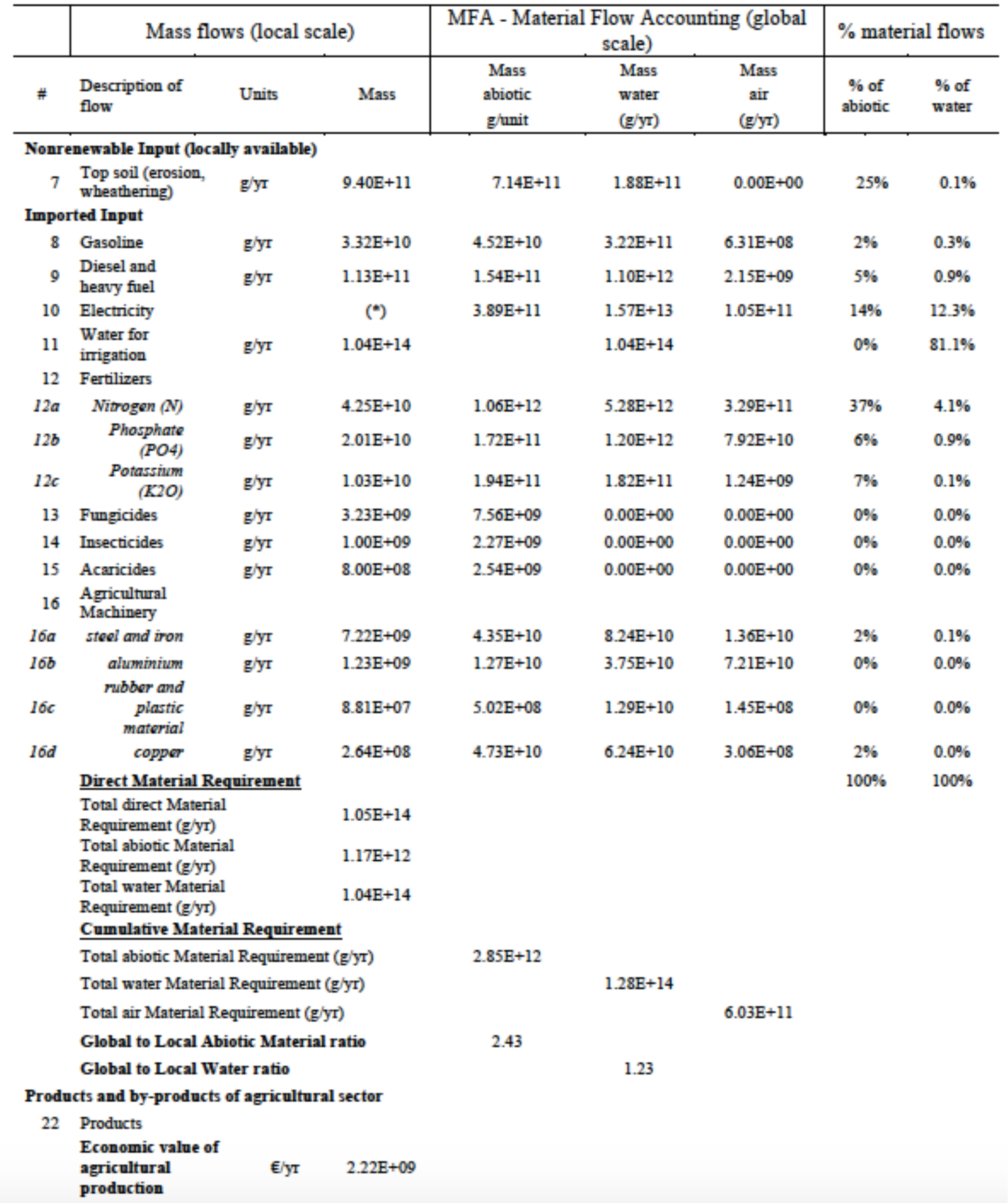
(rainfall+irrigation water)-(water evapotranspired)- (water used for photosynthesis and water content of crops and residues)=	2.74E+15	g/yr	

28 Topsoil used up

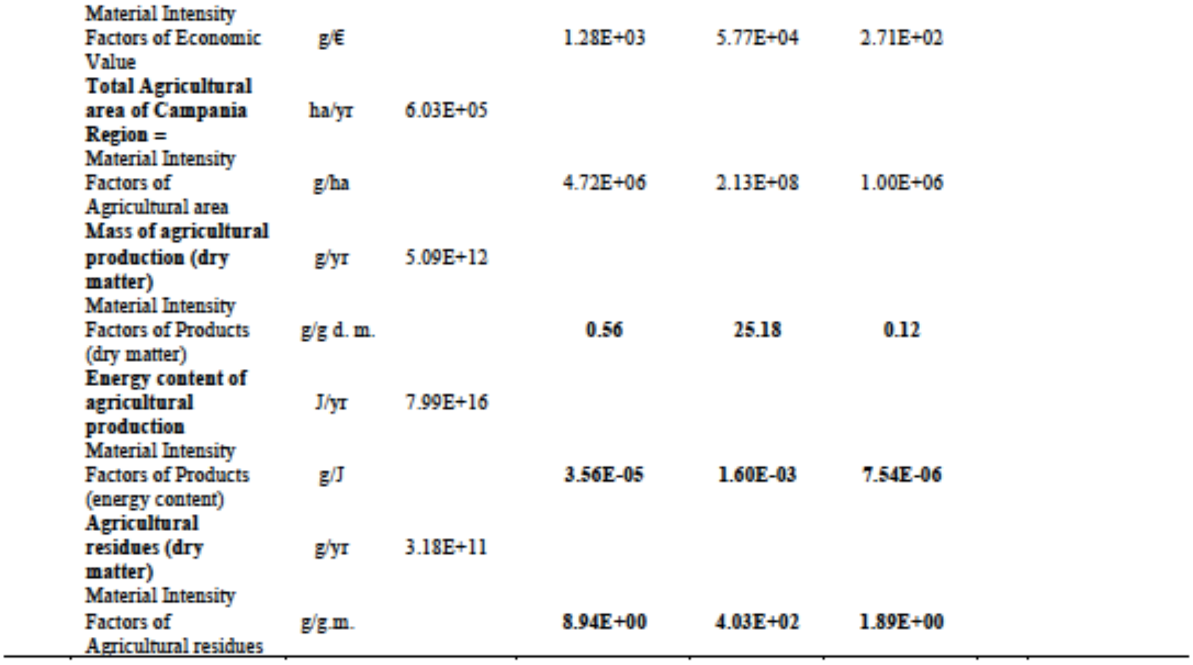
Topsoil enters the process as an essential "tool" for cropping.
When erosion occurs, topsoil is degraded and moved elsewhere.
It is therefore both an input and an output in the mass balance.

Mass of topsoil	9.40E+11	g/yr	(see above calculations for inputs)

Table A3 - Cumulative Material Demand (Year.....)



	Mass flows (local scale)			MFA - Material Flow Accounting (global scale)			% material flows	
#	Description of flow	Units	Mass	Mass abiotic g/unit	Mass water (g/yr)	Mass air (g/yr)	% of abiotic	% of water
Nonrenewable Input (locally available)								
7	Top soil (erosion, wheathering)	g/yr	9.40E+11	7.14E+11	1.88E+11	0.00E+00	25%	0.1%
Imported Input								
8	Gasoline	g/yr	3.32E+10	4.52E+10	3.22E+11	6.31E+08	2%	0.3%
9	Diesel and heavy fuel	g/yr	1.13E+11	1.54E+11	1.10E+12	2.15E+09	5%	0.9%
10	Electricity		(*)	3.89E+11	1.57E+13	1.05E+11	14%	12.3%
11	Water for irrigation	g/yr	1.04E+14		1.04E+14		0%	81.1%
12	Fertilizers							
12a	*Nitrogen (N)*	g/yr	4.25E+10	1.06E+12	5.28E+12	3.29E+11	37%	4.1%
12b	*Phosphate (PO4)*	g/yr	2.01E+10	1.72E+11	1.20E+12	7.92E+10	6%	0.9%
12c	*Potassium (K2O)*	g/yr	1.03E+10	1.94E+11	1.82E+11	1.24E+09	7%	0.1%
13	Fungicides	g/yr	3.23E+09	7.56E+09	0.00E+00	0.00E+00	0%	0.0%
14	Insecticides	g/yr	1.00E+09	2.27E+09	0.00E+00	0.00E+00	0%	0.0%
15	Acaricides	g/yr	8.00E+08	2.54E+09	0.00E+00	0.00E+00	0%	0.0%
16	Agricultural Machinery							
16a	*steel and iron*	g/yr	7.22E+09	4.35E+10	8.24E+10	1.36E+10	2%	0.1%
16b	*aluminium*	g/yr	1.23E+09	1.27E+10	3.75E+10	7.21E+10	0%	0.0%
16c	*rubber and plastic material*	g/yr	8.81E+07	5.02E+08	1.29E+10	1.45E+08	0%	0.0%
16d	*copper*	g/yr	2.64E+08	4.73E+10	6.24E+10	3.06E+08	2%	0.0%
	Direct Material Requirement						100%	100%
	Total direct Material Requirement (g/yr)		1.05E+14					
	Total abiotic Material Requirement (g/yr)		1.17E+12					
	Total water Material Requirement (g/yr)		1.04E+14					
	Cumulative Material Requirement							
	Total abiotic Material Requirement (g/yr)			2.85E+12				
	Total water Material Requirement (g/yr)				1.28E+14			
	Total air Material Requirement (g/yr)					6.03E+11		
	Global to Local Abiotic Material ratio			2.43				
	Global to Local Water ratio				1.23			
Products and by-products of agricultural sector								
22	Products							
	Economic value of agricultural production	€/yr	2.22E+09					



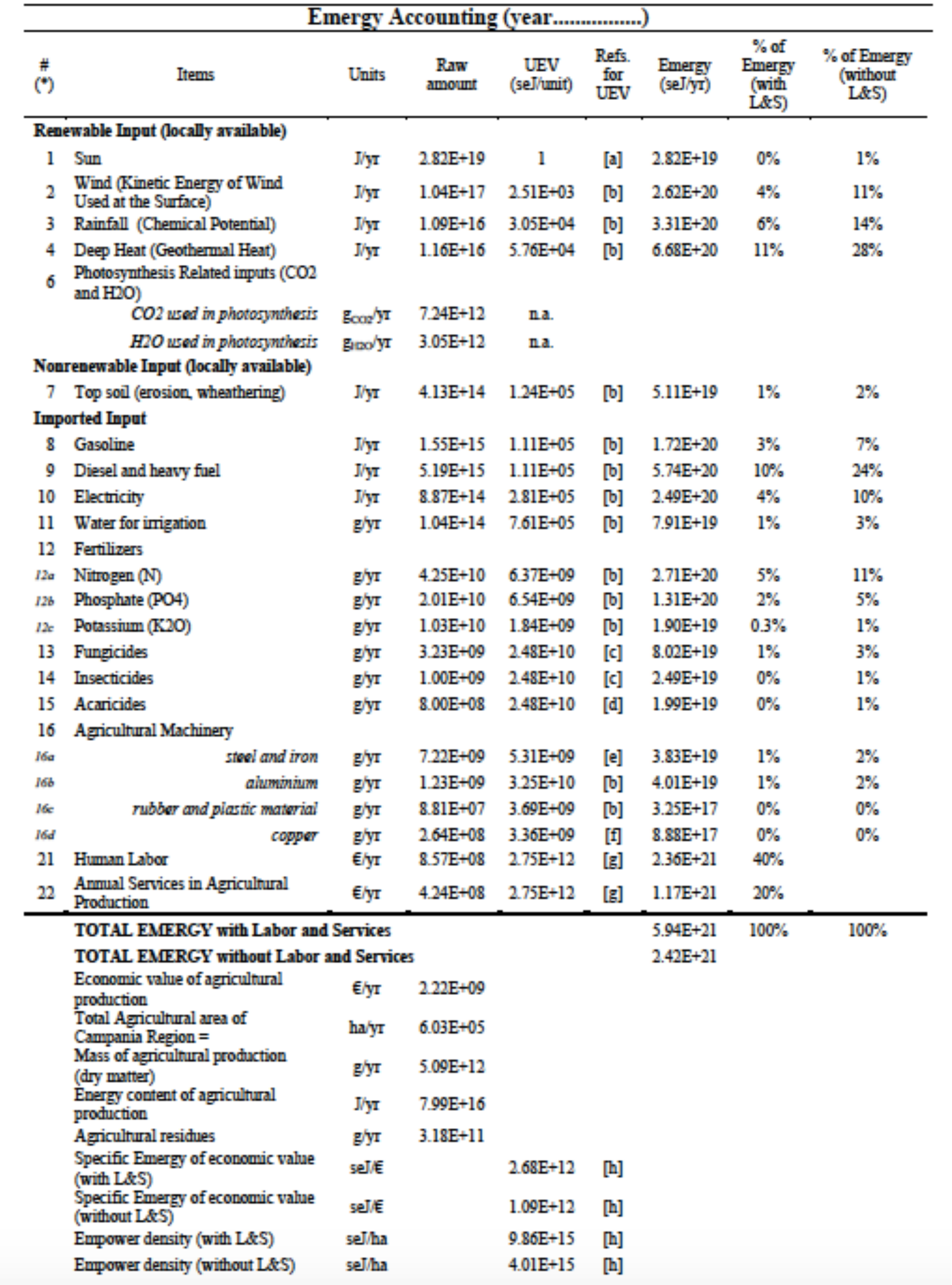
Material Intensity Factors of Economic Value	g/€		1.28E+03	5.77E+04	2.71E+02
Total Agricultural area of Campania Region =	ha/yr	6.03E+05			
Material Intensity Factors of Agricultural area	g/ha		4.72E+06	2.13E+08	1.00E+06
Mass of agricultural production (dry matter)	g/yr	5.09E+12			
Material Intensity Factors of Products (dry matter)	g/g d. m.		**0.56**	**25.18**	**0.12**
Energy content of agricultural production	J/yr	7.99E+16			
Material Intensity Factors of Products (energy content)	g/J		**3.56E-05**	**1.60E-03**	**7.54E-06**
Agricultural residues (dry matter)	g/yr	3.18E+11			
Material Intensity Factors of Agricultural residues	g/g.m.		**8.94E+00**	**4.03E+02**	**1.89E+00**

Table A4 - Cumulative Energy demand and Cumulative Emissions

(A) - Cumulative Energy Demand (year..................)						**(B) - Global emission flows (year............)**							
#	Flow	Units	Raw amount	Oil equiv. demand (g oil eq)	Energy demand (J)	Global CO_2 (**) (g CO_2)	Global CO (**) (g CO)	Global NO_x (**) (g NO_x)	Global SO_2 (**) (g SO_2)	Global Unburnt Hydrocarbon	Global N_2O (g N_2O)	Global CH_4 (g CH_4)	% of Energy demand
Imported Input													
8	8a. Gasoline	g/yr	3.32E+10	3.71E+10	1.55E+15	1.18E+11	2.77E+10	1.71E+08	8.26E+07	8.26E+07	1.48E+06	5.14E+07	10%
	8b Additional Energy (heavy fuel oil) for gasoline refining	g/yr	5.34E+09	5.44E+09	2.28E+14	1.67E+10	1.14E+06	4.89E+07	1.10E+08	4.10E+06	1.37E+05	6.83E+05	2%
9	9a Diesel and heavy fuel	g/yr	1.13E+11	1.24E+11	5.19E+15	3.92E+11	7.39E+08	1.68E+09	7.20E+07	7.20E+07	1.72E+07	1.61E+06	34%
	9b. Additional Energy (heavy fuel oil) for diesel refining	g/yr	2.36E+10	2.40E+10	1.00E+15	7.37E+10	5.02E+06	2.16E+08	4.87E+08	1.81E+07	6.03E+05	3.01E+06	7%
10	Electricity	J/yr	8.87E+14	5.30E+10	2.22E+15	1.37E+11	7.23E+07	3.39E+08	6.13E+08	2.12E+07	9.54E+05	3.62E+06	15%
11	Water for irrigation	g/yr	1.04E+14	1.37E+10	5.72E+14	4.19E+10	2.86E+06	1.23E+08	2.77E+08	1.03E+07	3.43E+05	1.72E+06	4%
12	Fertilizers												
12a	Nitrogen (N)	g/yr	4.25E+10	7.44E+10	3.12E+15	2.28E+11	1.56E+07	6.70E+08	1.51E+09	5.61E+07	1.87E+06	9.35E+06	21%
12b	Phosphate (PO4)	g/yr	2.01E+10	6.43E+09	2.69E+14	1.97E+10	1.35E+06	5.79E+07	1.31E+08	4.85E+06	1.62E+05	8.08E+05	2%
12c	Potassium (K2O)	g/yr	1.03E+10	2.26E+09	9.48E+13	6.95E+09	4.74E+05	2.04E+07	4.60E+07	1.71E+06	5.69E+04	2.84E+05	1%
13	Fungicides	g/yr	3.23E+09	4.33E+09	1.81E+14	1.33E+10	9.05E+05	3.89E+07	8.78E+07	3.26E+06	1.09E+05	5.43E+05	1%
14	Insecticides	g/yr	1.00E+09	1.27E+09	5.32E+13	3.90E+09	2.66E+05	1.14E+07	2.58E+07	9.57E+05	3.19E+04	1.59E+05	0%
15	Acaricides	g/yr	8.00E+08	1.74E+09	7.28E+13	5.34E+09	3.64E+05	1.57E+07	3.53E+07	1.31E+06	4.37E+04	2.18E+05	0%
16	Agricultural Machinery												
16a	*steel and iron*	g/yr	7.22E+09	6.57E+09	2.75E+14	2.02E+10	1.38E+06	5.91E+07	1.33E+08	4.95E+06	1.65E+05	8.25E+05	2%
16b	*aluminium*	g/yr	1.23E+09	6.61E+09	2.77E+14	2.03E+10	1.38E+06	5.95E+07	1.34E+08	4.98E+06	1.66E+05	8.30E+05	2%
16c	*rubber and plastic material*	g/yr	8.81E+07	2.64E+08	1.11E+13	8.11E+08	5.53E+04	2.38E+06	5.36E+06	1.99E+05	6.64E+03	3.32E+04	0%
16d	*fraction of copper*	g/yr	2.64E+08	5.84E+08	2.44E+13	1.79E+09	1.22E+05	5.25E+06	1.19E+07	4.40E+05	1.47E+04	7.33E+04	0%
Total direct and indirect energy cost				**3.62E+11**	**1.51E+16**								100%
Products and by-products of agricultural phase													
Economic value of agricultural production		€/yr	2.22E+09										
Total Agricultural area of Campania Region		ha/yr	6.03E+05										
Mass of agricultural production (dry matter)		g/yr	5.09E+12										
Energy content of agricultural production		J/yr	7.99E+16										
Agricultural residues (dry matter)		g/yr	3.18E+11										
Total direct and indirect emissions						**1.10E+12**	**2.85E+10**	**3.52E+09**	**3.76E+09**	**2.87E+08**	**2.34E+07**	**7.51E+07**	

Total emissions per unit of economic value (€)				495.46	12.86	1.59	1.70	0.13	0.01	0.03
Total emissions per unit of area (ha)				1.83E+06	4.74E+04	5.85E+03	6.25E+03	4.76E+02	3.88E+01	1.25E+02
Total emissions per unit of dry matter (g)				0.22	5.61E-03	6.92E-04	7.39E-04	5.64E-05	4.59E-06	1.48E-05
Total emissions per unit of energy content (J)				1.38E-05	3.57E-07	4.41E-08	4.71E-08	3.59E-09	2.93E-10	9.40E-10
Total emissions per unit of dry matter of residues (g)				3.46	8.97E-02	1.11E-02	1.18E-02	9.02E-04	7.34E-05	2.36E-04
Global/Local emissions				2.16	1.00	1.90	24.34	1.86	1.25	1.42
Global to local Energy ratio		1.98								
Energy Intensity Factors	unit/€	1.63E+02	6.82E+06							
Energy Intensity Factors	unit/ha	6.00E+05	2.51E+10							
Energy Intensity Factors	unit/g dry matter	0.07	2.97E+03							
Energy Intensity Factors	unit/J	4.53E-06	1.89E-01							
Energy Intensity Factors (Residues)	unit/g dry matter	1.14	4.76E+04							

Table A5 - Ecosystem Services in support to the process



Emergy Accounting (year……………)								
# (*)	Items	Units	Raw amount	UEV (seJ/unit)	Refs. for UEV	Emergy (seJ/yr)	% of Emergy (with L&S)	% of Emergy (without L&S)
Renewable Input (locally available)								
1	Sun	J/yr	2.82E+19	1	[a]	2.82E+19	0%	1%
2	Wind (Kinetic Energy of Wind Used at the Surface)	J/yr	1.04E+17	2.51E+03	[b]	2.62E+20	4%	11%
3	Rainfall (Chemical Potential)	J/yr	1.09E+16	3.05E+04	[b]	3.31E+20	6%	14%
4	Deep Heat (Geothermal Heat)	J/yr	1.16E+16	5.76E+04	[b]	6.68E+20	11%	28%
6	Photosynthesis Related inputs (CO_2 and H_2O)							
	CO_2 used in photosynthesis	g_{CO2}/yr	7.24E+12	n.a.				
	H_2O used in photosynthesis	g_{H2O}/yr	3.05E+12	n.a.				
Nonrenewable Input (locally available)								
7	Top soil (erosion, wheathering)	J/yr	4.13E+14	1.24E+05	[b]	5.11E+19	1%	2%
Imported Input								
8	Gasoline	J/yr	1.55E+15	1.11E+05	[b]	1.72E+20	3%	7%
9	Diesel and heavy fuel	J/yr	5.19E+15	1.11E+05	[b]	5.74E+20	10%	24%
10	Electricity	J/yr	8.87E+14	2.81E+05	[b]	2.49E+20	4%	10%
11	Water for irrigation	g/yr	1.04E+14	7.61E+05	[b]	7.91E+19	1%	3%
12	Fertilizers							
12a	Nitrogen (N)	g/yr	4.25E+10	6.37E+09	[b]	2.71E+20	5%	11%
12b	Phosphate (PO_4)	g/yr	2.01E+10	6.54E+09	[b]	1.31E+20	2%	5%
12c	Potassium (K_2O)	g/yr	1.03E+10	1.84E+09	[b]	1.90E+19	0.3%	1%
13	Fungicides	g/yr	3.23E+09	2.48E+10	[c]	8.02E+19	1%	3%
14	Insecticides	g/yr	1.00E+09	2.48E+10	[c]	2.49E+19	0%	1%
15	Acaricides	g/yr	8.00E+08	2.48E+10	[d]	1.99E+19	0%	1%
16	Agricultural Machinery							
16a	*steel and iron*	g/yr	7.22E+09	5.31E+09	[e]	3.83E+19	1%	2%
16b	*aluminium*	g/yr	1.23E+09	3.25E+10	[b]	4.01E+19	1%	2%
16c	*rubber and plastic material*	g/yr	8.81E+07	3.69E+09	[b]	3.25E+17	0%	0%
16d	*copper*	g/yr	2.64E+08	3.36E+09	[f]	8.88E+17	0%	0%
21	Human Labor	€/yr	8.57E+08	2.75E+12	[g]	2.36E+21	40%	
22	Annual Services in Agricultural Production	€/yr	4.24E+08	2.75E+12	[g]	1.17E+21	20%	
	TOTAL EMERGY with Labor and Services					5.94E+21	100%	100%
	TOTAL EMERGY without Labor and Services					2.42E+21		
	Economic value of agricultural production	€/yr	2.22E+09					
	Total Agricultural area of Campania Region =	ha/yr	6.03E+05					
	Mass of agricultural production (dry matter)	g/yr	5.09E+12					
	Energy content of agricultural production	J/yr	7.99E+16					
	Agricultural residues	g/yr	3.18E+11					
	Specific Emergy of economic value (with L&S)	seJ/€		2.68E+12	[h]			
	Specific Emergy of economic value (without L&S)	seJ/€		1.09E+12	[h]			
	Empower density (with L&S)	seJ/ha		9.86E+15	[h]			
	Empower density (without L&S)	seJ/ha		4.01E+15	[h]			

	Specific Emergy of unit of dry matter (with L&S)	seJ/g		1.17E+09	[h]			
	Specific Emergy of unit of dry matter (without L&S)	seJ/g		4.75E+08	[h]			
	Transformity (with L&S)	seJ/J		7.43E+04	[h]			
	Transformity (without L&S)	seJ/J		3.03E+04	[h]			
	Specific Emergy of unit of dry matter of residues (with L&S)	seJ/g		1.87E+10	[h]			
	Specific Emergy of unit of dry matter of residues (without L&S)	seJ/g		7.60E+09	[h]			

References for UEVs

[a] By definition

[b] After Odum et al., 2000

[c] After Brown and Arding, 1991

[d] After Ulgiati estimate from Odum 1996

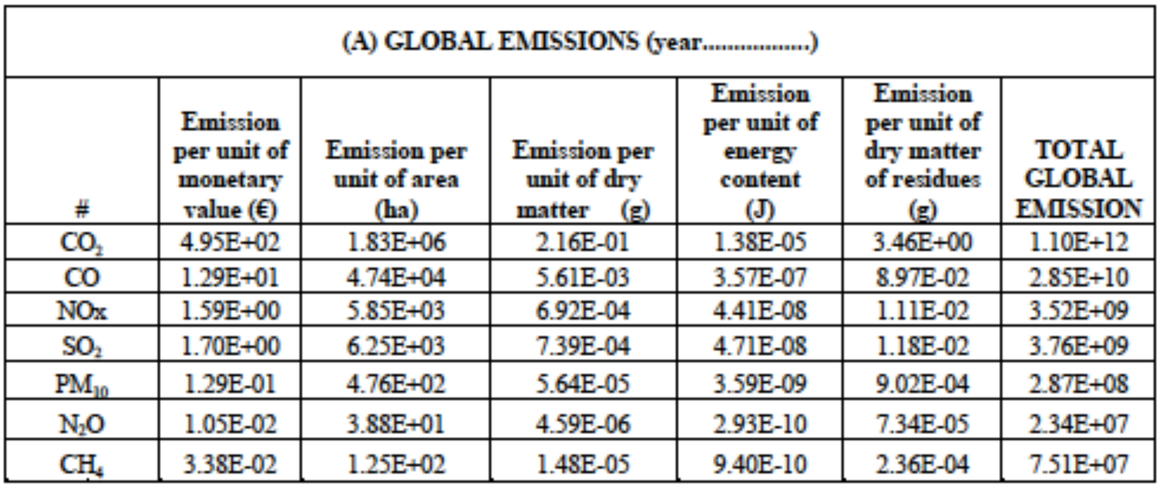
[e] Bargigli & Ulgiati, 2003

[f] Brown & Ulgiati, 2004

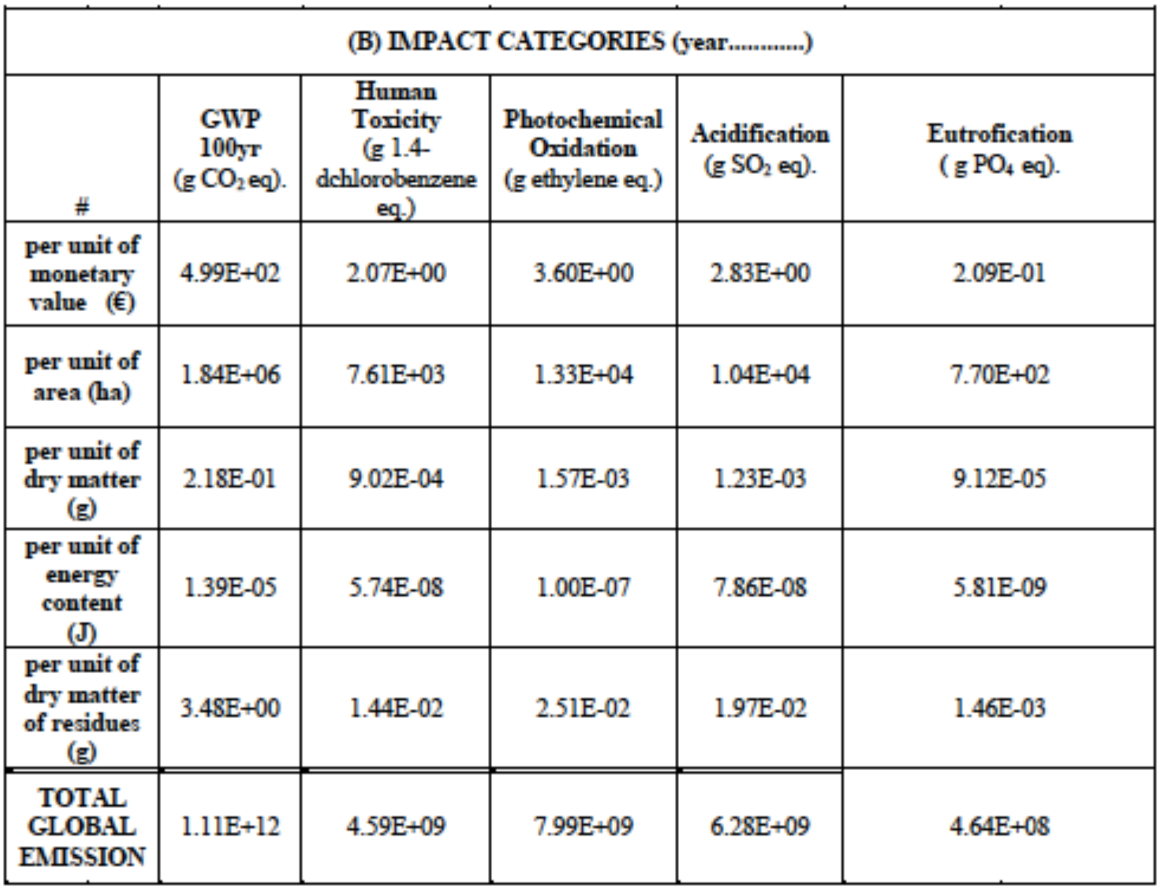
[g] After Ulgiati-Russi, 1999

[h] from calculation performed in this work.

Table A6 - Unit Cumulative Emissions (A) and Unit LCA Impacts (B)



(A) GLOBAL EMISSIONS (year.................)						
#	Emission per unit of monetary value (€)	Emission per unit of area (ha)	Emission per unit of dry matter (g)	Emission per unit of energy content (J)	Emission per unit of dry matter of residues (g)	TOTAL GLOBAL EMISSION
CO_2	4.95E+02	1.83E+06	2.16E-01	1.38E-05	3.46E+00	1.10E+12
CO	1.29E+01	4.74E+04	5.61E-03	3.57E-07	8.97E-02	2.85E+10
NOx	1.59E+00	5.85E+03	6.92E-04	4.41E-08	1.11E-02	3.52E+09
SO_2	1.70E+00	6.25E+03	7.39E-04	4.71E-08	1.18E-02	3.76E+09
PM_{10}	1.29E-01	4.76E+02	5.64E-05	3.59E-09	9.02E-04	2.87E+08
N_2O	1.05E-02	3.88E+01	4.59E-06	2.93E-10	7.34E-05	2.34E+07
CH_4	3.38E-02	1.25E+02	1.48E-05	9.40E-10	2.36E-04	7.51E+07



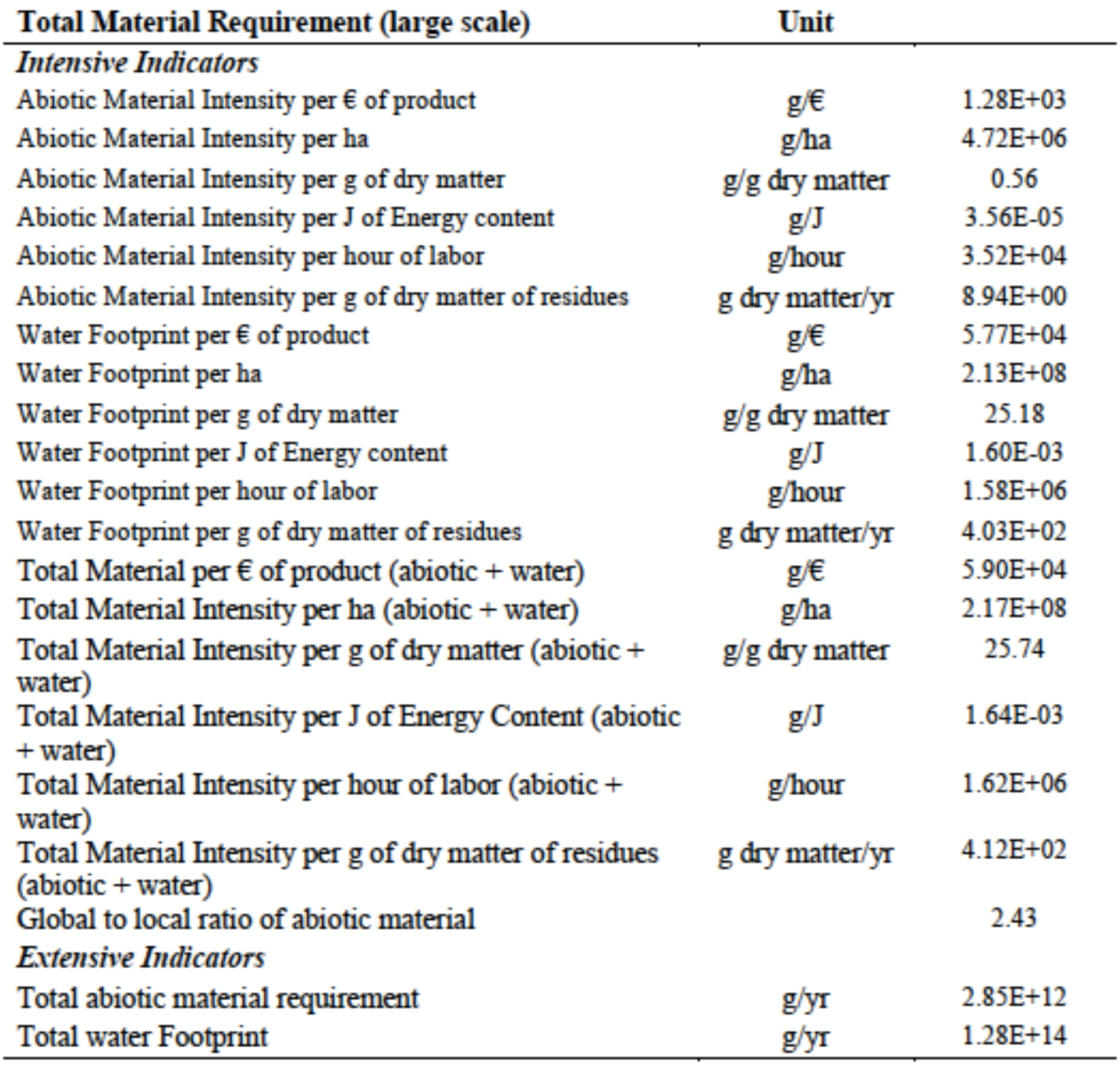
(B) IMPACT CATEGORIES (year............)					
#	GWP 100yr (g CO_2 eq).	Human Toxicity (g 1.4-dchlorobenzene eq.)	Photochemical Oxidation (g ethylene eq.)	Acidification (g SO_2 eq).	Eutrofication (g PO_4 eq).
per unit of monetary value (€)	4.99E+02	2.07E+00	3.60E+00	2.83E+00	2.09E-01
per unit of area (ha)	1.84E+06	7.61E+03	1.33E+04	1.04E+04	7.70E+02
per unit of dry matter (g)	2.18E-01	9.02E-04	1.57E-03	1.23E-03	9.12E-05
per unit of energy content (J)	1.39E-05	5.74E-08	1.00E-07	7.86E-08	5.81E-09
per unit of dry matter of residues (g)	3.48E+00	1.44E-02	2.51E-02	1.97E-02	1.46E-03
TOTAL GLOBAL EMISSION	1.11E+12	4.59E+09	7.99E+09	6.28E+09	4.64E+08

Table A7.1 - Prices and input&output flows

Prices	**Unit**	
Gasoline price	€/L	1.29
Diesel price	€/L	0.86
Electricity price	€/kWh	0.23
Water for irrigation	€/m3	0.19
Nitrogen (N) price	€/kg	0.61
Phosphate (PO4) price	€/kg	0.66
Potassium (K2O) price	€/kg	0.46
Fungicides price	€/kg	7.61
Insecticides price	€/kg	5.11
Acaricides price	€/kg	14.67
Unit labor cost	€/yr	10.58

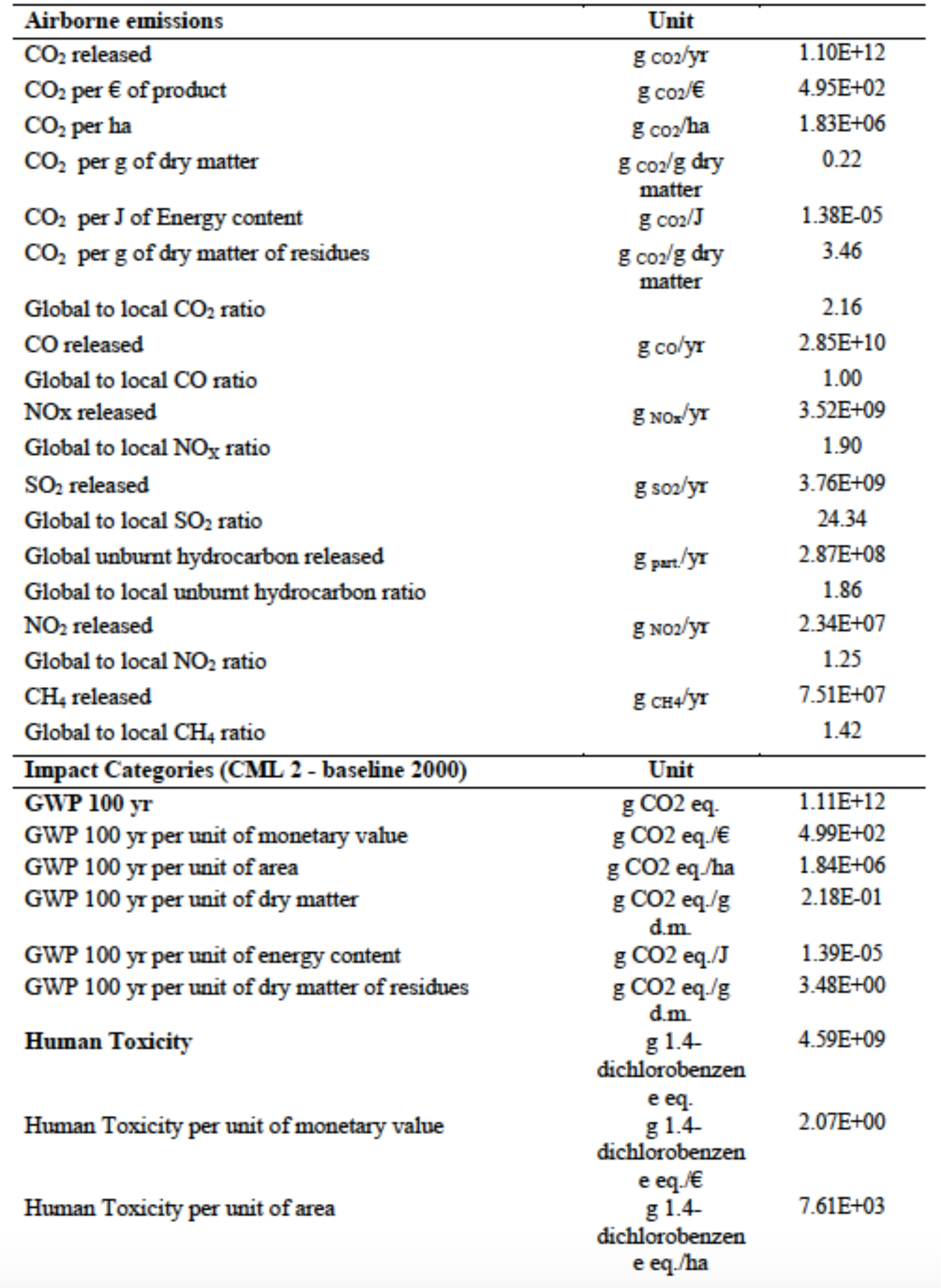
Input and output flows of Agricultural sector of Campania Region	**Unit**	
Direct supply, land use and product generated (process scale)		
Rainfall	g/yr	4.88E+15
Total land cropped	ha/yr	6.03E+05
Fertilizers (N + PO_4 + K_2O), TOTAL	g/yr	7.29E+10
Nitrogen (N)	g/yr	4.25E+10
Phosphate (PO_4)	g/yr	2.01E+10
Potassium (K_2O)	g/yr	1.03E+10
Electricity	J/yr	8.87E+14
Water for irrigation	g/yr	1.04E+14
Liquid fuels	J/yr	6.74E+15
Machinery	g/yr	8.81E+06
Direct Labor	hours/yr	8.10E+07
Direct Labor	€/yr	8.57E+08
Indirect labor (services)	€/yr	4.24E+08
Products		
Mass of agricultural production (dry matter)	g dry matter/yr	5.09E+12
Energy content of agricultural production	J/yr	7.99E+16
Economic value of agricultural production	€/yr	2.22E+09
Agricultural residues	t dry matter/yr	3.18E+05

Table A7.2 - Total Material Requirement Indicators



Total Material Requirement (large scale)	**Unit**	
Intensive Indicators		
Abiotic Material Intensity per € of product	g/€	1.28E+03
Abiotic Material Intensity per ha	g/ha	4.72E+06
Abiotic Material Intensity per g of dry matter	g/g dry matter	0.56
Abiotic Material Intensity per J of Energy content	g/J	3.56E-05
Abiotic Material Intensity per hour of labor	g/hour	3.52E+04
Abiotic Material Intensity per g of dry matter of residues	g dry matter/yr	8.94E+00
Water Footprint per € of product	g/€	5.77E+04
Water Footprint per ha	g/ha	2.13E+08
Water Footprint per g of dry matter	g/g dry matter	25.18
Water Footprint per J of Energy content	g/J	1.60E-03
Water Footprint per hour of labor	g/hour	1.58E+06
Water Footprint per g of dry matter of residues	g dry matter/yr	4.03E+02
Total Material per € of product (abiotic + water)	g/€	5.90E+04
Total Material Intensity per ha (abiotic + water)	g/ha	2.17E+08
Total Material Intensity per g of dry matter (abiotic + water)	g/g dry matter	25.74
Total Material Intensity per J of Energy Content (abiotic + water)	g/J	1.64E-03
Total Material Intensity per hour of labor (abiotic + water)	g/hour	1.62E+06
Total Material Intensity per g of dry matter of residues (abiotic + water)	g dry matter/yr	4.12E+02
Global to local ratio of abiotic material		2.43
Extensive Indicators		
Total abiotic material requirement	g/yr	2.85E+12
Total water Footprint	g/yr	1.28E+14

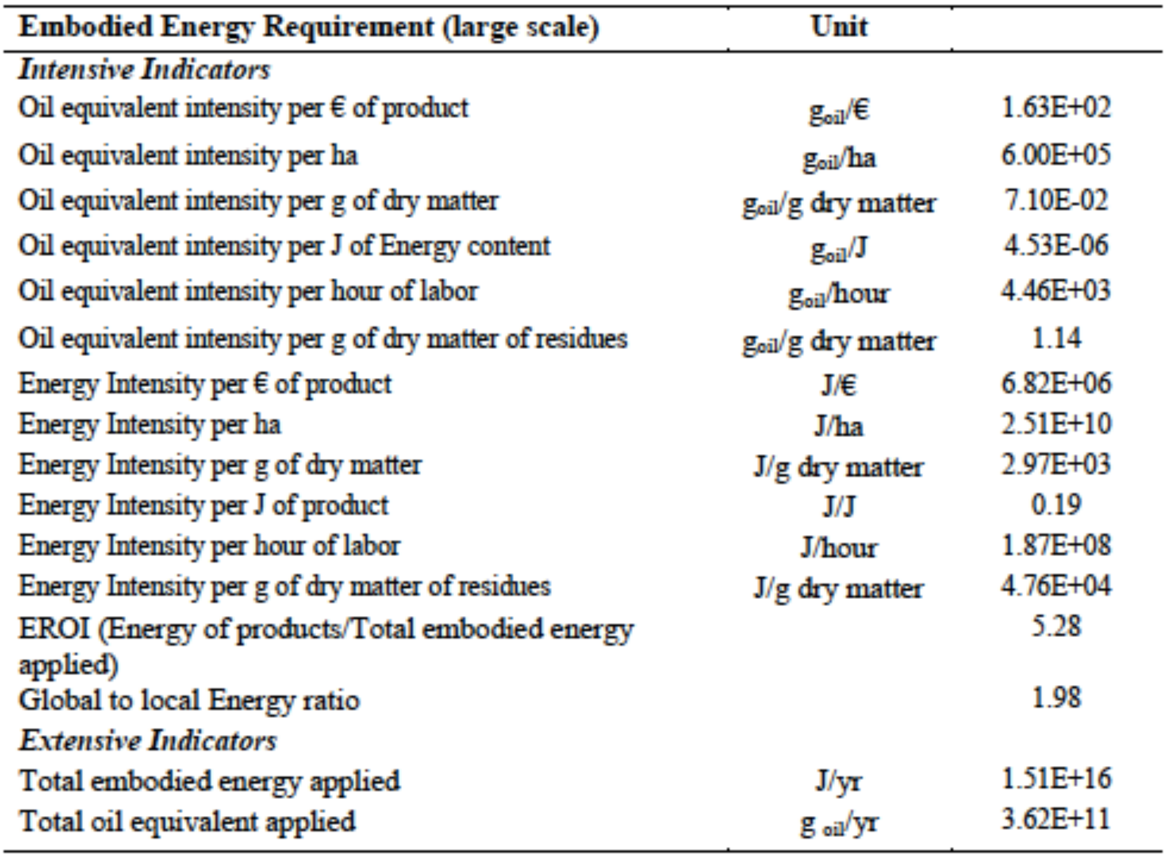
Table A7.3 - Airborne Emissions Indicators



Airborne emissions	**Unit**	
CO_2 released	g $_{co2}$/yr	1.10E+12
CO_2 per € of product	g $_{co2}$/€	4.95E+02
CO_2 per ha	g $_{co2}$/ha	1.83E+06
CO_2 per g of dry matter	g $_{co2}$/g dry matter	0.22
CO_2 per J of Energy content	g $_{co2}$/J	1.38E-05
CO_2 per g of dry matter of residues	g $_{co2}$/g dry matter	3.46
Global to local CO_2 ratio		2.16
CO released	g $_{co}$/yr	2.85E+10
Global to local CO ratio		1.00
NOx released	g $_{NOx}$/yr	3.52E+09
Global to local NO_X ratio		1.90
SO_2 released	g $_{so2}$/yr	3.76E+09
Global to local SO_2 ratio		24.34
Global unburnt hydrocarbon released	g $_{part.}$/yr	2.87E+08
Global to local unburnt hydrocarbon ratio		1.86
NO_2 released	g $_{NO2}$/yr	2.34E+07
Global to local NO_2 ratio		1.25
CH_4 released	g $_{CH4}$/yr	7.51E+07
Global to local CH_4 ratio		1.42
Impact Categories (CML 2 - baseline 2000)	**Unit**	
GWP 100 yr	g CO2 eq.	1.11E+12
GWP 100 yr per unit of monetary value	g CO2 eq./€	4.99E+02
GWP 100 yr per unit of area	g CO2 eq./ha	1.84E+06
GWP 100 yr per unit of dry matter	g CO2 eq./g d.m.	2.18E-01
GWP 100 yr per unit of energy content	g CO2 eq./J	1.39E-05
GWP 100 yr per unit of dry matter of residues	g CO2 eq./g d.m.	3.48E+00
Human Toxicity	g 1.4-dichlorobenzene eq.	4.59E+09
Human Toxicity per unit of monetary value	g 1.4-dichlorobenzene eq./€	2.07E+00
Human Toxicity per unit of area	g 1.4-dichlorobenzene eq./ha	7.61E+03

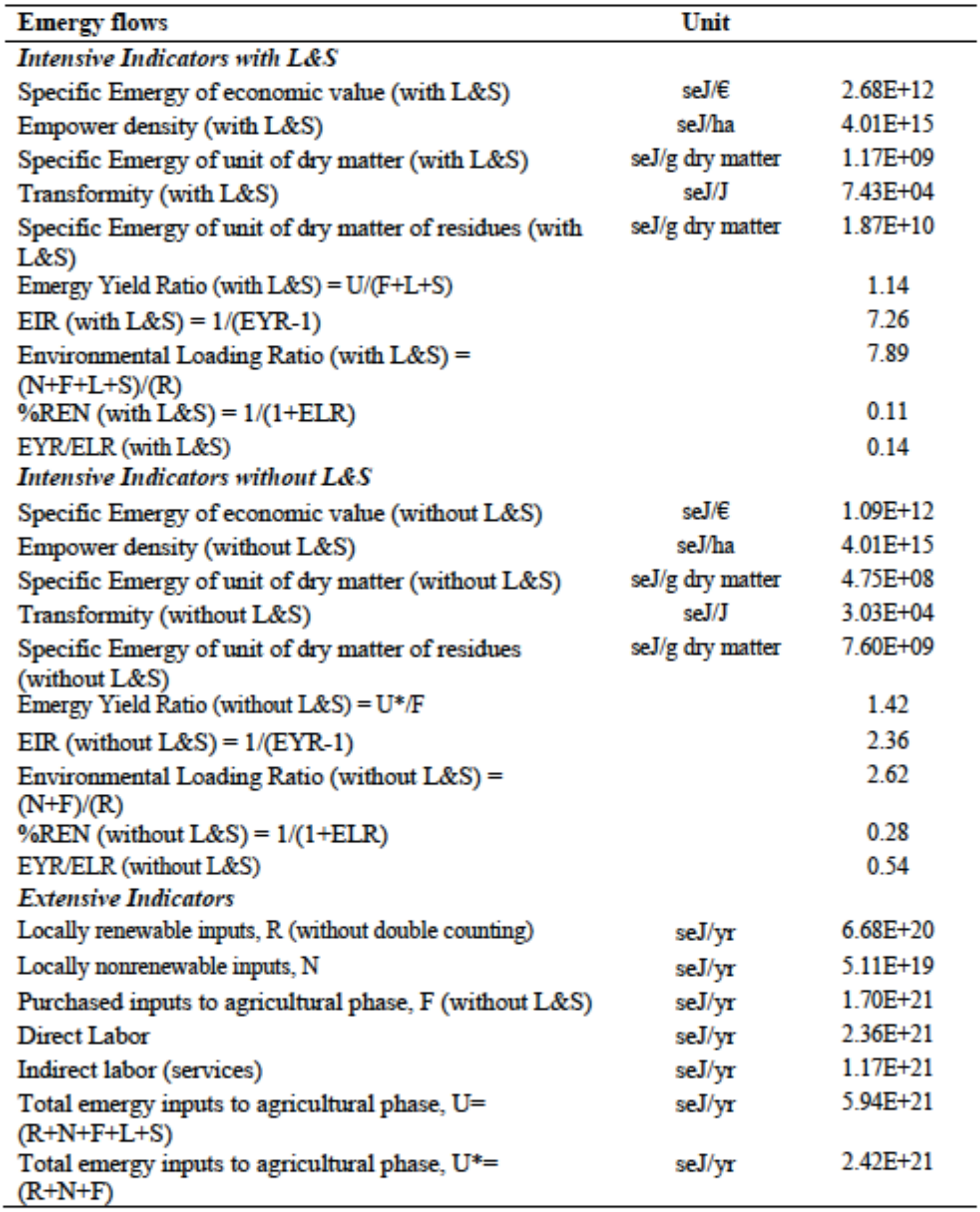
Human Toxicity per unit of dry matter	g 1.4-dichlorobenzene eq./g d.m.	9.02E-04
Human Toxicity per unit of energy content	g 1.4-dichlorobenzene eq./J	5.74E-08
Human Toxicity per unit of dry matter of residues	g 1.4-dichlorobenzene eq./g d.m.	1.44E-02
Photochemical Oxidation	g ethylene eq.	7.99E+09
Photochemical Oxidation per unit of monetary value	g ethylene eq./€	3.60E+00
Photochemical Oxidation per unit of area	g ethylene eq./ha	1.33E+04
Photochemical Oxidation per unit of dry matter	g ethylene eq./g d.m.	1.57E-03
Photochemical Oxidation per unit of energy content	g ethylene eq./J	1.00E-07
Photochemical Oxidation per unit of dry matter of residues	g ethylene eq./g d.m.	2.51E-02
Acidification	g SO2 eq.	6.28E+09
Acidification per unit of monetary value	g SO2 eq./€	2.83E+00
Acidification per unit of area	g SO2 eq./ha	1.04E+04
Acidification per unit of dry matter	g SO2 eq./g d.m.	1.23E-03
Acidification per unit of energy content	g SO2 eq./J	7.86E-08
Acidification per unit of dry matter of residues	g SO2 eq./g d.m.	1.97E-02
Eutrofication	g PO4 eq.	4.64E+08
Eutrofication per unit of monetary value	g PO4 eq./€	2.09E-01
Eutrofication per unit of area	g PO4 eq./ha	7.70E+02
Eutrofication per unit of dry matter	g PO4 eq./g d.m.	9.12E-05
Eutrofication per unit of energy content	g PO4 eq./J	5.81E-09
Eutrofication per unit of dry matter	g PO4 eq./g d.m.	1.46E-03

Table A7.4 - Cumulative Energy Indicators



Embodied Energy Requirement (large scale)	**Unit**	
Intensive Indicators		
Oil equivalent intensity per € of product	g_{oil}/€	1.63E+02
Oil equivalent intensity per ha	g_{oil}/ha	6.00E+05
Oil equivalent intensity per g of dry matter	g_{oil}/g dry matter	7.10E-02
Oil equivalent intensity per J of Energy content	g_{oil}/J	4.53E-06
Oil equivalent intensity per hour of labor	g_{oil}/hour	4.46E+03
Oil equivalent intensity per g of dry matter of residues	g_{oil}/g dry matter	1.14
Energy Intensity per € of product	J/€	6.82E+06
Energy Intensity per ha	J/ha	2.51E+10
Energy Intensity per g of dry matter	J/g dry matter	2.97E+03
Energy Intensity per J of product	J/J	0.19
Energy Intensity per hour of labor	J/hour	1.87E+08
Energy Intensity per g of dry matter of residues	J/g dry matter	4.76E+04
EROI (Energy of products/Total embodied energy applied)		5.28
Global to local Energy ratio		1.98
Extensive Indicators		
Total embodied energy applied	J/yr	1.51E+16
Total oil equivalent applied	g $_{oil}$/yr	3.62E+11

Table A7.5 - Emergy Indicators



Emergy flows	**Unit**	
Intensive Indicators with L&S		
Specific Emergy of economic value (with L&S)	seJ/€	2.68E+12
Empower density (with L&S)	seJ/ha	4.01E+15
Specific Emergy of unit of dry matter (with L&S)	seJ/g dry matter	1.17E+09
Transformity (with L&S)	seJ/J	7.43E+04
Specific Emergy of unit of dry matter of residues (with L&S)	seJ/g dry matter	1.87E+10
Emergy Yield Ratio (with L&S) = U/(F+L+S)		1.14
EIR (with L&S) = 1/(EYR-1)		7.26
Environmental Loading Ratio (with L&S) = (N+F+L+S)/(R)		7.89
%REN (with L&S) = 1/(1+ELR)		0.11
EYR/ELR (with L&S)		0.14
Intensive Indicators without L&S		
Specific Emergy of economic value (without L&S)	seJ/€	1.09E+12
Empower density (without L&S)	seJ/ha	4.01E+15
Specific Emergy of unit of dry matter (without L&S)	seJ/g dry matter	4.75E+08
Transformity (without L&S)	seJ/J	3.03E+04
Specific Emergy of unit of dry matter of residues (without L&S)	seJ/g dry matter	7.60E+09
Emergy Yield Ratio (without L&S) = U*/F		1.42
EIR (without L&S) = 1/(EYR-1)		2.36
Environmental Loading Ratio (without L&S) = (N+F)/(R)		2.62
%REN (without L&S) = 1/(1+ELR)		0.28
EYR/ELR (without L&S)		0.54
Extensive Indicators		
Locally renewable inputs, R (without double counting)	seJ/yr	6.68E+20
Locally nonrenewable inputs, N	seJ/yr	5.11E+19
Purchased inputs to agricultural phase, F (without L&S)	seJ/yr	1.70E+21
Direct Labor	seJ/yr	2.36E+21
Indirect labor (services)	seJ/yr	1.17E+21
Total emergy inputs to agricultural phase, U= (R+N+F+L+S)	seJ/yr	5.94E+21
Total emergy inputs to agricultural phase, U*= (R+N+F)	seJ/yr	2.42E+21

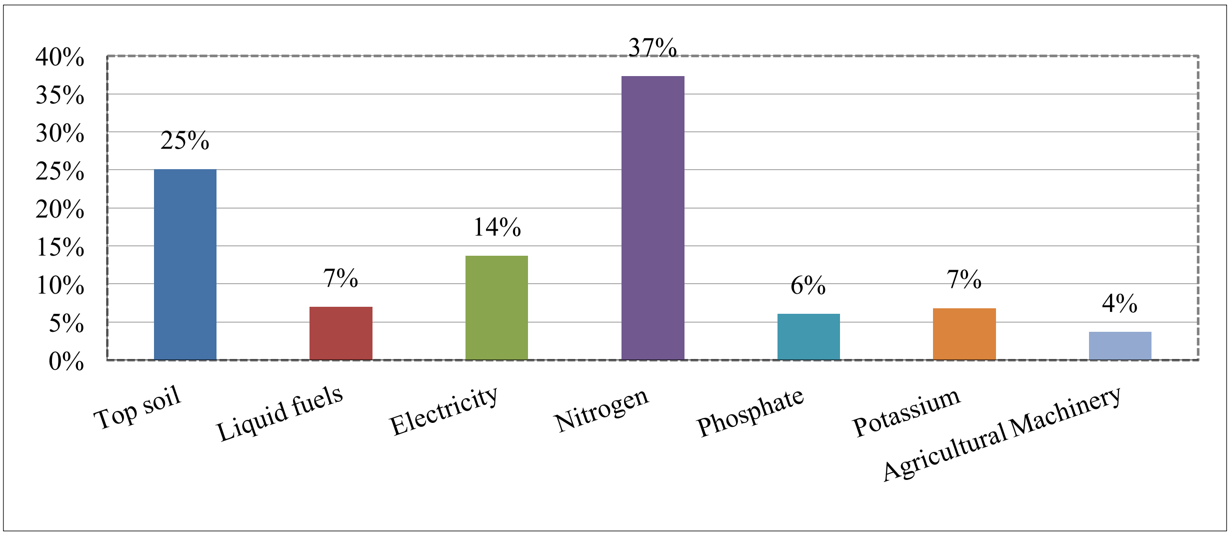


Figure A1. Abiotic materials demand (%)

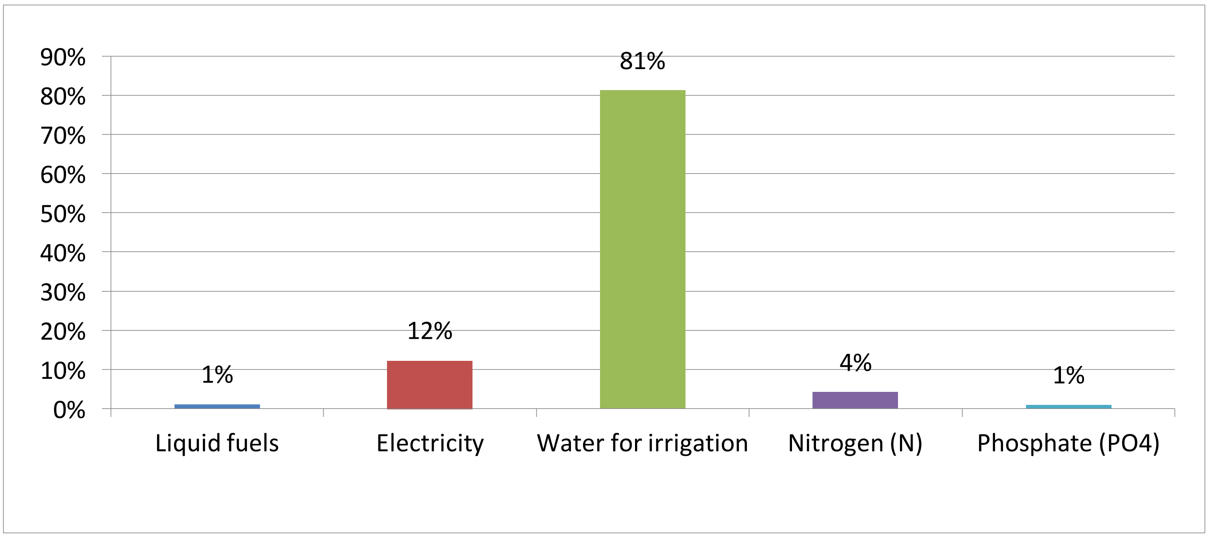


Figure A2. Water Material Demand (%)

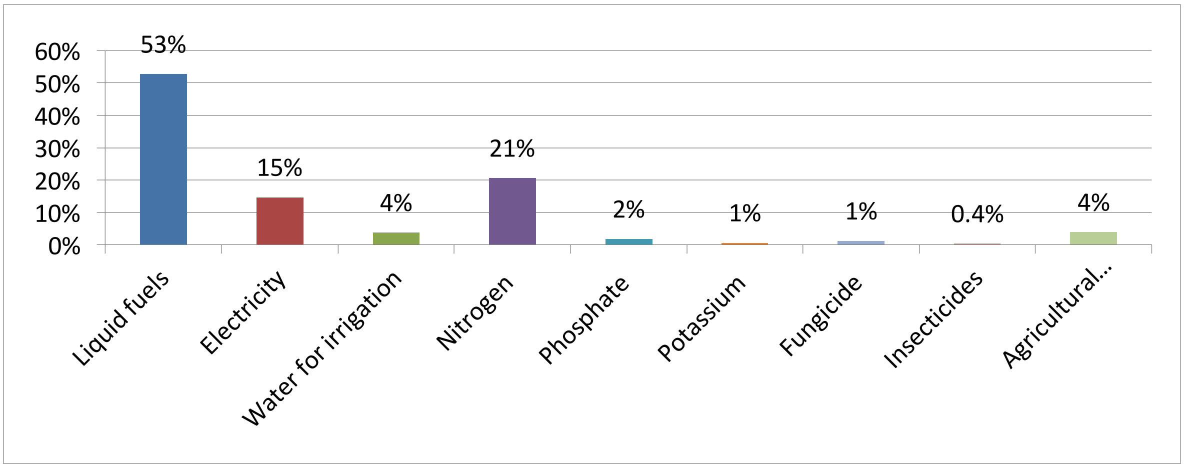


Figure A3. Energy Demand (%)

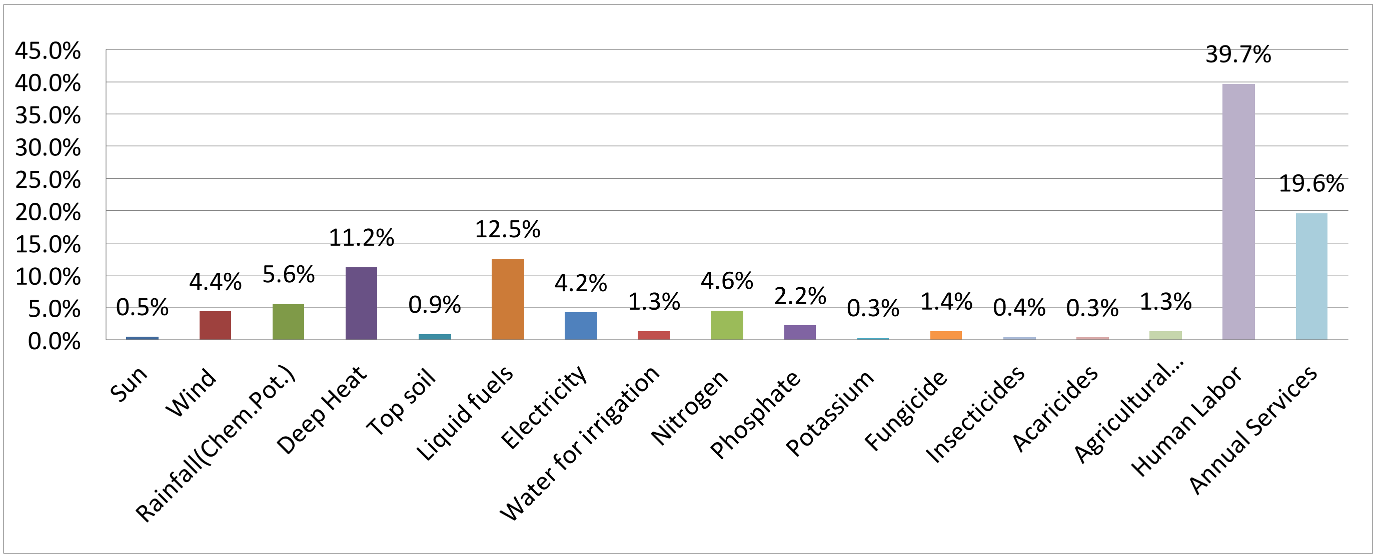


Figure A4. Emergy demand, with L&S (%)

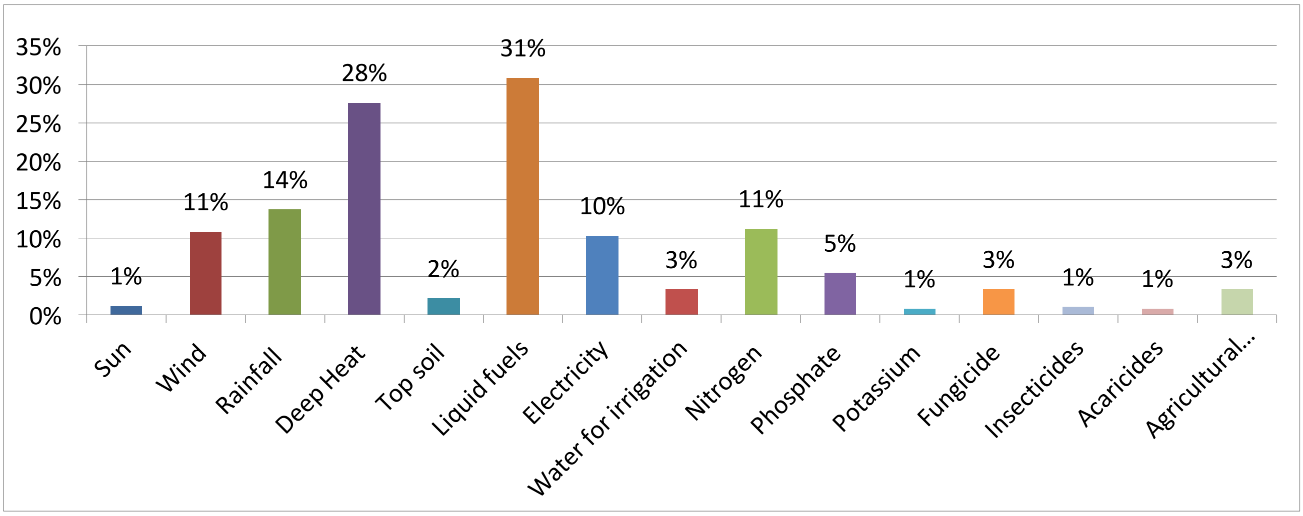


Figure A5. Emergy demand, without L&S (%)