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Original Citation

Georgopoulou, Anneza, Angelis-Dimakis, Athanasios, Arampatzis, George and Assimacopoulos, Dionysis (2014) Eco-efficiency assessment in the agricultural sector: The case of fresh form tomato crop in Phthiotida. In: Proceedings of the 12th International Conference on Protection and Restoration of the Environment. GRAFIMA, Thessaloniki, Greece, pp. 935-941. ISBN 978-960-88490-6-8

Eco-efficiency assessment in the agricultural sector: The case of fresh form tomato crop in Phthiotida

A. Georgopoulou, A. Angelis-Dimakis, G. Arampatzis, and D. Assimacopoulos*
Environmental and Energy Management Research Unit, School of Chemical Engineering,
National Technical University of Athens, Athens, Greece

*Corresponding author: E-mail: assim@chemeng.ntua.gr, Tel +30 210 7723218

Abstract
During the last two decades, the concept of eco-efficiency has been recognized as a suitable measure of progress towards a greener and more sustainable economy. The prefix "eco-" refers to both economic and ecological (environmental) performance. Therefore, it becomes critical to develop eco-efficiency metrics for measuring environmental and economic performance of a system. The current paper presents a methodological framework that attempts to explore the use of eco-efficiency indicators in meso-level water use systems and through them to assess the impact of new and innovative technologies in such systems. The environmental performance is expressed through the use of environmental midpoint impact categories while the economic performance is measured using the total value added to the system's product due to water use. The proposed approach has been applied to a water use system of the agricultural sector, and more specifically to the fresh form tomato crop production in Phthiotida.

Keywords: eco-efficiency, water use systems, agricultural sector

1. INTRODUCTION

The term eco-efficiency was introduced in the late 1980s and appeared in academic literature for the first time in 1989 [1]. The first official definition was given by the World Business Council for Sustainable Development in 1991 and combined the concepts of economic welfare and competitiveness with the ecological impact of products throughout their lifecycle, the use of natural resources and the environmental carrying capacity [2]. OECD has defined eco-efficiency as the efficiency with which ecological resources are used to meet human needs and expressed it as the ratio of an output (the value of products and services produced by a firm, sector or economy as a whole) divided by the input (the sum of environmental pressures generated by the firm, the sector or the economy) [3]. Eco-efficiency has become, during the recent years, an important concept of environmental decision making, serving both as a policy objective and as a measure of progress towards sustainability. It has been closely linked with eco-innovation, as it combines the concepts of economic welfare and competitiveness with the ecological impact of products or processes throughout their lifecycle.

The present paper describes a methodological framework for the eco-efficiency assessment of a meso-level water use system. Eco-efficiency assessment is a quantitative tool which enables the study of the environmental impacts of a product or service system along with its added value. Within eco-efficiency assessment, environmental impacts are assessed using a Life Cycle Assessment (LCA) oriented approach. Thus, an eco-efficiency assessment shares many important principles and approaches with LCA such as functional unit, life-cycle inventory and life cycle impact assessment [4, 5]. The meso-level is defined as an intermediate scale between the macro level and the micro level. It may be linked to a spatial unit (region, river basin) or to a firm (e.g. a multi-national enterprise) and should be large enough to have substantial impact and importance for studying the implications of policies and technological developments [6]. The developed methodology has been applied to a water use system of the agricultural sector.

2. METHODOLOGY

2.1 Goal and Scope Definition

The objective of the developed methodology is to assess the eco-efficiency of a meso-level water-use system. Before selecting and calculating the eco-efficiency indicators, the boundaries and the characteristics of the studied system, as well as the functional unit, have to be identified. A generic meso-level water use system can be represented as a network of unit processes. Each process represents an activity, implementing one or more technologies, where generic materials (water, raw materials, energy and other supplementary resources) are transformed into products, while releasing emissions to the environment (air, land, water) or into the system water flow. The boundaries of the studied system encompass all the processes related to the water supply and the water use chains and can be grouped into four generic stages, as depicted in Figure 1. The functional unit sets the scale for the comparison of two or more products or services delivered to the consumers [4, 7]. The main purpose of a functional unit is to provide a reference to which results are normalized and compared. Possible functional units for a meso-level water use system could be: (a) one unit of product/service delivered or (b) one unit (e.g. m^3) of water used.

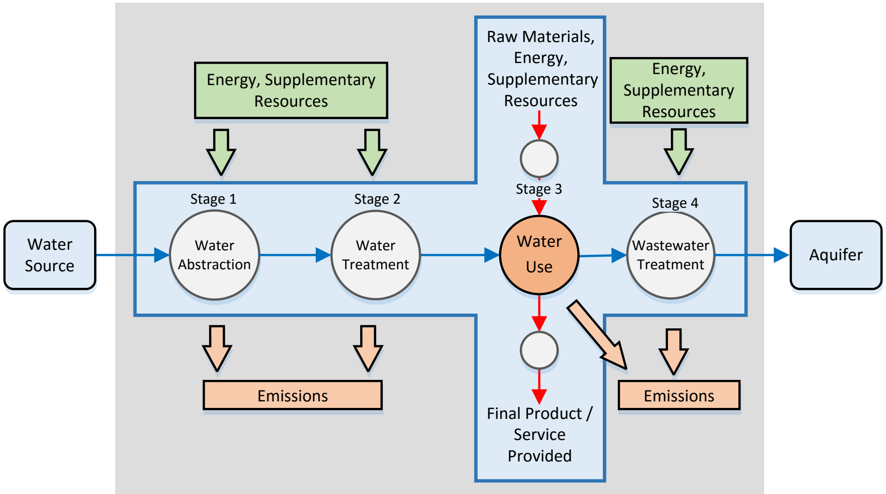

Figure 1. Generic meso-level water system

2.2 Eco-efficiency Assessment

2.2.1 Environmental Assessment

The assessment of the environmental performance follows a life-cycle oriented approach using midpoint impact categories. An inventory of flows entering and leaving every process in the system is created and, based on that, the significance of potential environmental impacts is evaluated. The results of the inventory, expressed as elementary flows, are assigned to impact categories according to the contribution of the resource/emission to different environmental problems, using standard characterization factors. The environmental impact for impact category *c* is expressed as a score (ES_c) in a unit common to all contributions within the category. It can be easily calculated using the flows from the inventory analysis and the characterization factors, as follows:

$$ES_c = \sum_r cf_{r,c} \times f_r + \sum_e cf_{e,c} \times f_e \qquad (1)$$

where: $cf_{r,c}$ the characterization factor of resource r for the impact category c, $cf_{e,c}$ the characterization factor of emission e for the impact category c (both retrieved from LCA databases), and f_r, f_e the elementary flows of resource r and emission e respectively.

Most LCA studies and databases neglect the impacts from the use of freshwater [8] and there is no standardized environmental midpoint indicator for the freshwater resource depletion [7]. However, since water consumption is a main component of the studied system, freshwater depletion cannot be neglected. The methodology proposed by Mila i Canals [9] and suggested by JRC [7] is used, and it is based on the Freshwater Ecosystem Impact (FEI) indicator, defined as:

$$FEI = f_{w,abs} \times WTA \qquad (2)$$

where $f_{w,abs}$ is the flow of freshwater abstracted and WTA is the water withdrawal to availability ratio.

2.2.2 Value Assessment

The economic performance of a system is monitored by using the Total Value Added (*TVA*) to the product due to water use, expressed in monetary units per period and per functional unit. It is estimated as:

$$TVA = EVU + VP_{BP} - TFC_{WS} - TFC_{WW} - FC \qquad (3)$$

where *EVU* is the total economic value from water use, VP_{BP} the income generated from any by-products of the system, TFC_{WS} the total financial cost related to water supply provision for rendering the water suitable for the specific use, TFC_{WW} the total financial cost related to wastewater treatment and *FC* the annual equivalent future cash flow generated by the introduction of new technologies in the system. The total economic value from water use can be calculated by subtracting the expenses for all the non-water inputs as well as the costs related to emissions in the water use stage from the total value of the products.

2.2.3 Eco-efficiency Indicators

The Eco-Efficiency Indicator for the impact category c (EEI_C) is defined as the ratio of the economic performance indicator divided by an environmental performance indicator of the system:

$$EEI_C = \frac{TVA}{ES_C} \qquad (4)$$

3. THE CASE OF FRESH FORM TOMATO CROP IN PHTHIOTIDA

The proposed approach has been applied to the agricultural sector, and more specifically to the fresh form tomato crop production in Phthiotida, which is one of the regional units of Greece, located in the administrative region of Central Greece. Geographically, it is surrounded by several mountain ranges and it is part of the valley of river Spercheios. Due to its morphology, the regional climate varies between the northern and the southern part. The arable land is characterized by lowland continental conditions (hot and dry summer-mild and wet winter).

Tomato is a seasonal vegetable, cultivated in the summer, which requires large volumes of water and systematic irrigation at regular intervals, especially after the fruit set. Although tomato can be grown in any type of soil and is tolerant to high temperatures (up to 38^{o}C), its sensitivity in parasites and potential diseases suggests the systematic implementation of pesticides and fertilizers. 11.9% of the annual fresh form tomato crop in Greece is produced in Central Greece and more specifically 5% is produced in Phthiotida [10]. The term “fresh form” implies that the product is consumed, without any further processing, after the fruit has set.

3.1 System boundaries & Functional unit

The studied system is illustrated in Figure 2 and consists of two different chains, the water supply chain and the tomato production chain, which are intersected at the irrigation process. Each process is represented by a node, the black solid arrows represent the water supply chain, the black dotted arrows the tomato production chain, the gray solid arrows all the incoming supplementary resources (i.e. diesel, fertilizers and pesticides) and the gray dotted arrows all the outgoing pollutants. The functional unit depends on the reference flow selected each time. In this study, two different cases are investigated: (i) when the unit of product delivered is the flow of interest, the functional unit is defined as 1 ton of tomato and (ii) when the quantity of interest is the water used for the production purposes then the functional unit is 1 m^3 of water used in the production of each crop.

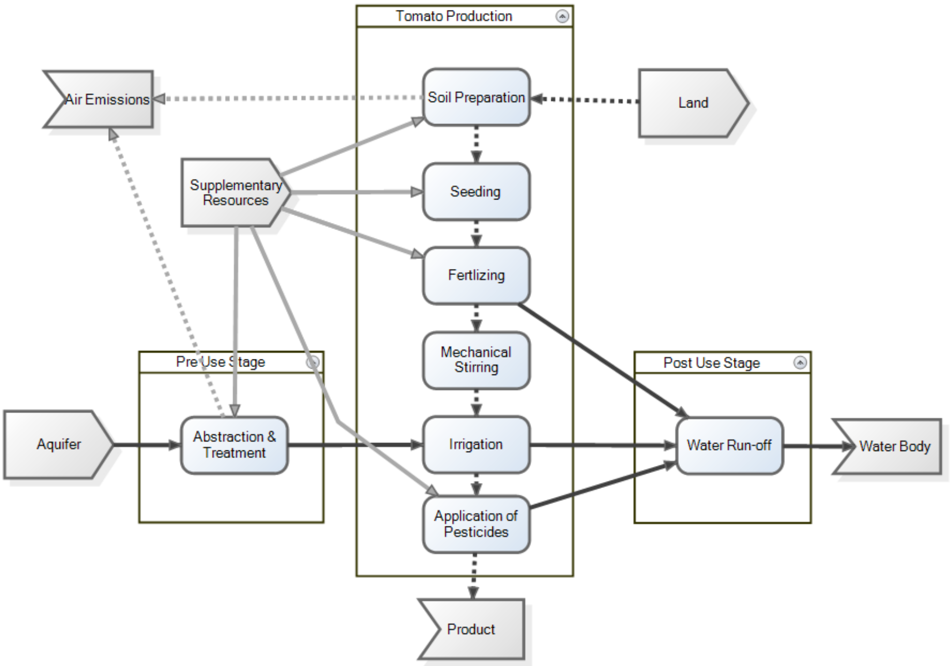

Figure 2. Stages of water value chain and tomato crop

3.2 Environmental assessment

The average tomato yield is estimated to be 37.5 tons per hectare and the annual crop water requirements are assumed to be 7133 m^3 per hectare [11, 12]. For the farm irrigation, a drip irrigation system is used, with average field efficiency of 80%. It is also assumed that each ton of tomato requires 24 kg of fertilizer 20-20-20 and 0.4 kg of pesticide [11]. Water is abstracted using diesel pumps with a specific consumption of 0.035 L per m^3 of water. The environmental performance of the system is assessed through eight, relevant to the agricultural sector, environmental impact categories. The characterization factors included in the CML-IA database are used for the calculation of the environmental impacts [13]. The results are presented in Table 1.

3.3 Value assessment

The total value added to the tomato from the use of water is calculated based on the unit costs of supplementary resources, which were provided by the local suppliers. In addition, the fixed and the variable water supply cost in Phthiotida is 14.8 €/yr and 1 €/m^3, respectively. Finally, according to the Ministry of Development, Competitiveness, Infrastructure, Transport and Networks, the average unit price of fresh form tomato was 1.87 €/kg in 2011. The total value added to the product from the water use is 1246.4 €/tn or 5.82 €/m^3 of water used.

3.4 Eco-efficiency assessment

Based on the environmental and value assessment, the eight relevant eco-efficiency indicators are calculated and presented in Table 1. It is apparent that the three major environmental impacts of the studied system (with the lowest eco-efficiency value) are: (a) climate change, due to diesel consumption for water abstraction and soil preparation, (b) freshwater ecotoxicity due to the use of pesticides and (c) freshwater depletion. Thus, the upgrading of the system through innovative technologies should aim at improving these three key indicators. Indicative options include a more efficient irrigation system, the replacement of the diesel pump with a solar one and the promotion of green pesticides.

Table 1. Environmental and eco-efficiency indicators

Midpoint Impact Category	Unit	ES_C (in Unit/m^3)	ES_C (in Unit/tn tomato)	EEI_C (in €/Unit)
Climate change	$kgCO_{2eq}$	0.225	48.21	25.8
Eutrophication	$kgPO_4{}^{3}{}_{-,eq}$	0.022	4.62	270
Acidification	$kgSO^{2-}{}_{,eq}$	0.002	0.42	2990
Photochemical oxidation	kg $C_2H_{4,eq}$	< 0.001	0.013	99760
Human toxicity	$kg1,4DCB_{,eq}$	0.006	1.22	1025
Freshwater Ecotoxicity	$kg1,4DCB_{,eq}$	0.178	38.00	32.8
Terrestrial Ecotoxicity	$kg1,4DCB_{,eq}$	< 0.001	0.011	115407
Freshwater Depletion	m^3	0.188	40.12	31.1

3.5 Value chain upgrade

The option that will be examined is the installation of a sub-drip irrigation system. It is assumed that its investment cost is 5000€/ha, its annual operation and maintenance cost is equal to 12% of the investment cost, its lifetime is 15 years and the average field efficiency is 90% [14]. The TVA from water use in that case is 1230.9 €/tn or 5.75 €/m^3 of water used. Figure 3 presents the relative change in the eight eco-efficiency indicators of the upgraded system compared to those of the current situation (baseline scenario). The application of the sub-drip irrigation system shows a significant improvement in the freshwater and the climate change, as the abstracted water and consequently the diesel consumption are reduced for this stage. It also positively affects all the other environmental impacts related to diesel consumption, without significantly deteriorating the ecotoxicity (freshwater and terrestrial) and the eutrophication. A slight decrease observed in these three indicators is due to the lower TVA.

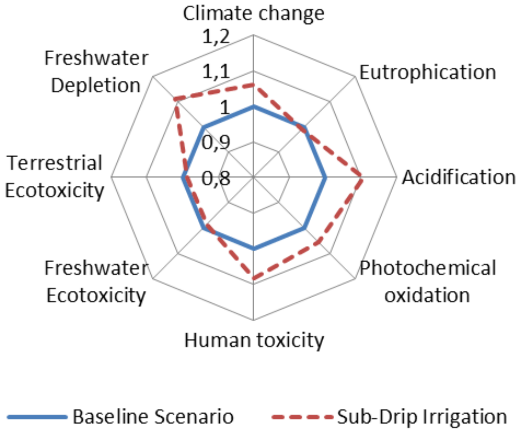

Figure 3. Comparison of eco-efficiency indicators in the two scenarios

4. CONCLUSIONS

The concept of eco-efficiency can be used as a suitable measure of progress towards a greener and more sustainable economy. This paper presented a methodological framework that attempts to explore the use of eco-efficiency indicators in meso-level water use systems. This approach was applied to the water use system of tomato production in Phthiotida. The baseline scenario is compared to the implementation of an alternative irrigation technology (sub-drip irrigation) in order to improve the eco-efficiency performance. The analysis indicates that the installation of a sub-surface irrigation system significantly improves the performance of the system in five out of eight eco-efficiency indicators. Based on the findings, it can be said that the proposed methodology gives reliable results and can be expanded and applied to other water use systems.

Acknowledgements
The methodology presented in the paper arises from 'EcoWater: Meso-level eco-efficiency indicators to assess technologies & their uptake in water use sectors', a collaborative research project of the 7th Framework Programme, grant agreement no. 282882, coordinated by the National Technical University of Athens (NTUA).

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