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Food security and sustainable agriculture in Lebanon: An environmental accounting framework

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ABSTRACT

World population is expected to approach 9.7 billion by 2050. This scenario will lead to an increase in food demand, worsening environmental problems due to intensive agricultural productions. For this reason, one of the major challenges is to attain both food security and sustainable agriculture worldwide. While food security is aimed at ensuring a constant and healthy food supply over time, sustainable agriculture plays a key role for the maintenance of resilient agroecosystems. In this study, we implemented a multicriteria accounting framework to explore the environmental performance and sustainability of agricultural production in Lebanon at both farm and national level. An extensive field study was conducted to collect data on natural and human-driven flows supporting nine main agricultural production systems in different Lebanese regions. The investigated cropping systems were assessed in terms of environmental costs and impacts by jointly applying the following environmental accounting methods: gross energy requirement (GER), material flow accounting (MFA), emergy accounting, and emissions accounting and contribution to impact categories. At national level, the total emergy demand resulted $5.46 \cdot 10^{21}$ sej yr^{-1}, while the total GER was $1.81 \cdot 10^{10}$ MJ yr^{-1}. The total water and abiotic demand resulted $6.27 \cdot 10^{8}$ t yr^{-1} and $2.64 \cdot 10^{6}$ t yr^{-1}, respectively. Finally, the total contribution to global warming potential (GWP) resulted $1.45 \cdot 10^{12}$ g CO_2 eq yr^{-1}, while the acidification potential (AP) and the human toxicity (HT) resulted $5.79 \cdot 10^{9}$ g SO_2 eq yr^{-1} and $6.88 \cdot 10^{9}$ g 1,4-DCB eq yr^{-1}. At farm level, orange production showed the lowest environmental performance due to a high use of water, diesel, and fertilizers. Instead, olive production showed the best environmental performance thanks to a low requirement of mass and energy inputs, and human labour, confirming the advantages of environmental friendly practices. The results of this study can help both farmers and policy makers in charge for ensuring a sustainable management of agricultural production while providing access to safe, healthy, and nutritious food for a growing population. Finally, a set of biophysical and socio-economic indicators is proposed for integrating the environmental accounting with a socio-economic perspective on food security and sustainable agriculture.

1. Introduction

It is projected that the world population will reach 9.7 billion in 2050 (UN, 2017) and, as a consequence, the overall food production is expected to increase by approximately 70% (FAO, 2009; Tscharntke et al., 2012). The increase of food production will mainly occur in developing countries through intensive agricultural practices based on a massive use of chemical pesticides, fertilizers, fossil fuels and machineries (Meyfroidt, 2018; Qi et al., 2018a). These practices affect soil quality and fertility, cause biodiversity loss, and generate emissions of greenhouse-gases and environmental pollution. Nevertheless, the depletion of natural capital stocks (such as soil and water) results in environmental degradation, threatening the long-term food supply (Clark and Tilman, 2017; Costanza et al., 1997, 2014; Folke et al., 2011; Häyhä and Franzese, 2014; World Resources Institute, 2013).

According to the World Food Summit (1996), "food security exists when all people at all times have both physical and economic

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access to safe, sufficient and nutritious food able to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996, p. 3). The issue of food insecurity arises any time the individual food consumption fails in sustaining a healthy diet.

Four main dimensions of food security have been identified: 1) *availability*, the supply of food in an area, 2) *access*, the physical and economic capability of people to have access to food, 3) *utilization*, the proper consumption of food, and 4) *stability*, the sustainability of food production and supply (FAO et al., 2017).

Agriculture is a strategic sector providing commodities on which food security of nations is based (Gasparatos, 2011). Considering the massive environmental impact of conventional agricultural productions, one of the major challenges is to attain both food security and sustainable agriculture worldwide. A balance should be met between large-scale food production responding to the society's growing needs and the maintenance of resilient agroecosystems (Bullock et al., 2017; Kazemi et al., 2018; Tendall et al., 2015). This goal requires the implementation of a new paradigm in agriculture based on practices capable of minimizing the environmental impact while ensuring the quality of food products and environment (Clark and Tilman, 2017; Gomiero et al., 2011; Qi et al., 2018b).

A modern approach to the issue of food security and sustainable agriculture should entail an interdisciplinary perspective including economic, social, and environmental aspects. In this context, environmental accounting can be a useful tool for assessing environmental costs and impacts of food production (Franzese et al., 2009, 2013; Weber, 2018).

Several studies explored the environmental performance and sustainability of agricultural production systems using environmental accounting. Ulgiati et al. (1993) assessed the sustainability of the Italian agricultural system through the emergy accounting method, highlighting the role of energy quality and environmental inputs. Franzese et al. (2009) compared two energy-based environmental accounting methods (G.E.R. and emergy accounting) to explore similarities in calculation procedures and differences in their theoretical features by jointly applying them for the assessment of cropping systems. Pimentel (2009) evaluated energy inputs in food crop production in developed and developing nations. Franzese et al. (2013) implemented an integrated assessment framework to investigate the environmental performance and sustainability of agricultural and farming production systems in the Toledo River Basin (Brazil). Wang et al. (2014) assessed grain production systems on large-scale farms in China. Farajian et al. (2018) modeled agricultural energy demand in Iran from 1988 to 2014. Yan et al. (2017) investigated energy use and related emissions of the agricultural sector of 17 European Union (EU) countries from 1995 to 2012. Costello et al. (2015) compared environmental impact metrics at farm and national scale for United States agricultural commodities. Dong et al. (2013) developed a carbon footprint accounting model to assess agricultural production in the Chinese province of Zhejiang.

In this study, the environmental performance and sustainability of agricultural production in Lebanon was explored by implementing a multicriteria environmental accounting framework. In particular, the study assessed agricultural production in Lebanon in terms of: (1) energy cost, (2) material cost, (3) emergy cost, (4) generated emissions, and (5) their contribution to relevant impact categories. Performance indicators calculated at farm level for nine main cropping systems were used to obtain results at national level. Finally, a set of biophysical and socio-economic indicators is proposed for integrating environmental accounting with a socio-economic perspective on food security and sustainable agriculture.

2. Materials and methods

2.1. The study area

Lebanon is a small Eastern Mediterranean country covering a total area of 10,452 km^2. Its population has reached about 6 million people with a density of 575 persons km^{-2} (Asmar, 2011; The world bank, 2016). Moreover, refugees constitute 30% of Lebanon population resulting in the highest per capita concentration of refugees in the world (UNHCR, 2015a,b; UNHCR et al., 2016).

Lebanon is characterized by a Mediterranean climate along with fertile soils and a relative abundance of water (FAO, 2014; MOA, 2014). Despite these optimal climatic conditions and availability of natural resources, agricultural production has decreased during the last years, especially due to the occupation of agricultural lands by Syrian refugees (MOE, 2014, 2015).

The main produced and consumed agricultural crops in Lebanon are potato, tomato, orange, apple, lemon, wheat, banana, grape, cucumber, and olive (MOA, 2014; MOE et al., 2015; Verner et al., 2013).

Over the past 50 years, the Lebanese agricultural sector has been characterized by a shift from low-input extensive farming to intensive practices causing environmental and soil quality degradation (FAO, 2014; Ghadban et al., 2013). Although agricultural practices are highly intensive, the Lebanese agricultural production is not capable of satisfying the national demand and, approximately, 80% of food needs are covered by imports (UNEP, 2005; WFP, 2017).

The massive food import (about 80% of the country's food needs, Halabi and Ghanem, 2016) and the decrease of national agricultural production have also caused an increase of food prices, resulting in an increase of social inequality and difficult access to food for poorer people (Farjalla et al., 2010). Currently, about 24% of Lebanese population is food insecure while about 38% of the total Syrian population living in Lebanon does not have adequate access to food (OCHA, 2015; UNHCR et al., 2017).

2.2. Data collection

A field study was conducted to investigate the nine main crops produced and consumed at national level (Table 1). In particular, data were collected through structured field interviews to agricultural farmers selected in five main Lebanese regions: Beqaa, Baalbak-Hermel, Mount Lebanon, North Lebanon and South Lebanon. For each crop, from 5 to 9 farmers were interviewed. In total, twenty-seven farmers were interviewed. Farmers and regions were selected depending on the different investigated crops. For example, since potato and wheat crops are mainly located in the Beqaa region, 8 farmers for each of these two crops were interviewed in this region. Similarly, since grape production is mainly located in the North and Beqaa regions, data collection was conducted in these two regions. In addition, to obtain representative data, new farmers and farms covering small areas (lower than 1 ha) were excluded from the study. Data about the following annual input to and output from agricultural production systems were collected: agricultural areas and harvest, applied human labour, water, diesel, machineries, lubricants, pesticides, fertilizers, and seeds. Machineries were accounted for by considering their specific lifetime.

Data collected were used to calculate average input and output flows for each investigated crop. The value of free environmental flows (solar radiation, rain, wind, and geothermal flow) and the average value of topsoil loss were estimated from literature (Dawtec, 2013; Hassan, 2011; Geowatt AG Resources and Poyry, 2014; El Hage Hassan et al., 2015; MoEW and UNDP, 2014).

Table 1
Main cultivated crops in Lebanon, areas, and annual production at national level (MOA, 2010).

Crop	Olive	Wheat	Potato	Grape	Apple	Orange	Citrus	Tomato	Cucumber
Area (ha)	56,800	39,800	18,900	12,024	11,800	8240	5896	3098	1896
Production (tons yr^{-1})	85,200	111,400	425,000	108,000	138,100	177,000	152,400	194,500	87,200

Table 2 shows the inventory of the main input and output flows for the nine selected crops, calculated for one average hectare.

2.3. The multicriteria environmental accounting framework

In this study, a multicriteria environmental accounting framework was implemented to assess the environmental performance and sustainability of selected agricultural productions in Lebanon.

The applied environmental accounting methods can be assigned to two broad categories: (1) “upstream methods” (i.e., Material Flow Accounting, Gross Energy Requirement, and Emergy Accounting), and (2) “downstream methods” (i.e., CML). Upstream methods are concerned with inputs to agricultural production systems and account for environmental resources depletion. Instead, downstream methods are related to outputs and assess emissions and their impacts on environmental matrices (Buonocore et al., 2012, 2014; Franzese et al., 2009, 2013; Nikodinoska et al., 2017; Ulgiati et al., 2006).

The assessment was implemented through the following steps:

1. Identification of spatial and temporal boundaries of the investigated cropping systems;
2. Modelling of the agricultural productions through a systems diagram (Odum, 1996);
3. Inventory of the main inputs to and outputs from cropping systems;
4. Assessment of cumulative (direct + indirect) matter, energy and emergy demands; assessment of main emissions and their contribution to impact categories;
5. Calculation of a set of indicators of environmental performance and sustainability.

The multicriteria environmental accounting framework generates a large set of intensive and extensive indicators. Intensive indicators are calculated per unit of generated product (functional unit) and are independent on the physical size of the investigated system. Instead, extensive indicators are directly related to the physical size of the investigated system and take into account for the total consumption of resources and generation of emissions.

Intensive indicators were first calculated at farm level per hectare of each cropping system. Then, they were multiplied by the total area of each cropping system at national level to obtain extensive indicators showing the total environmental costs and impacts of Lebanese agriculture.

2.3.1. Material flow accounting

The Material Flow Accounting (MFA) method (Hinterberger and Stiller, 1998; Schmidt-Bleek, 1993) aims at evaluating the direct and indirect material flows supporting the production of goods and services. The idea behind MFA comes from the recognition that flows of material resources are limitedly available and, therefore, the production of goods and services should be based on an

Table 2
Inventory of the main annual input and output flows calculated at farm level for one average hectare of the nine selected crops in the year 2017.

Crop	Potato	Wheat	Olive	Orange	Citrus	Grape	Apple	Cucumber	Tomato
Input									
Local Renewable resources									
Solar radiation (J/year)	5.52E+13	5.52E+13	5.52E+13	5.52E+13	5.52E+13	5.52E+13	5.52E+13	5.52E+13	5.52E+13
Wind (J/year)	4.81E+09	4.81E+09	4.81E+09	4.81E+09	4.81E+09	4.81E+09	4.81E+09	4.81E+09	4.81E+09
Rain (J/year)	7.61E+09	7.61E+09	7.61E+09	7.61E+09	7.61E+09	7.61E+09	7.61E+09	7.61E+09	7.61E+09
Geothermal flow (J/year)	1.58E+10	1.58E+10	1.58E+10	1.58E+10	1.58E+10	1.58E+10	1.58E+10	1.58E+10	1.58E+10
Local Non renewable resources									
Net loss of topsoil (J/year)	5.32E+09	5.32E+09	5.32E+09	5.32E+09	5.32E+09	5.32E+09	5.32E+09	5.32E+09	5.32E+09
Water, Irrigation (J/year)	3.09E+10	3.04E+09	7.11E+08	1.42E+11	7.12E+10	2.87E+10	1.12E+10	3.82E+10	5.02E+10
Imported Resources									
Diesel (J/year)	7.12E+10	1.80E+10	1.20E+10	1.42E+11	7.12E+10	2.63E+10	7.12E+10	4.53E+10	7.13E+10
Lubricants (J/year)	8.35E+08	4.14E+08	3.98E+08	1.52E+09	1.52E+09	1.52E+09	2.22E+09	8.77E+08	1.09E+09
Machinery (Steel) (g/year)	7.96E+05	4.45E+05	2.09E+05	1.86E+05	1.86E+05	2.87E+05	2.34E+05	2.16E+05	2.16E+05
Machinery (Plastic) (g/year)	8.84E+04	4.95E+04	2.32E+04	2.07E+04	2.07E+04	3.19E+04	2.60E+04	2.40E+04	2.40E+04
Fertilizers, Nitrogen (g/year)	2.50E+05	3.37E+05	3.24E+05	6.36E+05	6.36E+05	1.06E+05	2.42E+05	4.23E+05	3.64E+05
Fertilizers, Potassium (g/year)	2.08E+05	4.36E+04	2.34E+05	6.36E+05	6.36E+05	1.06E+05	2.29E+05	3.05E+05	4.05E+05
Fertilizers, Phosphate (g/year)	2.10E+05	3.58E+04	8.95E+04	1.96E+05	1.96E+05	1.40E+05	1.25E+05	2.57E+05	3.31E+05
Pesticide and Herbicide (g/year)	2.18E+04	2.95E+03	1.90E+04	1.71E+05	1.71E+05	3.04E+04	8.54E+04	6.26E+04	4.15E+04
Seeds (g/year)	2.23E+06	2.36E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Labour (L.L./year)	2.70E+06	1.89E+05	2.21E+06	1.08E+07	6.91E+06	2.55E+06	1.81E+06	2.22E+07	3.16E+07
Services (L.L./year)	3.23E+07	6.56E+06	7.74E+06	1.19E+07	8.25E+06	9.15E+06	8.33E+06	9.06E+06	8.97E+06
Output									
Harvest, fresh weight (g/year)	3.56E+07	5.94E+06	1.45E+07	5.40E+07	5.40E+07	2.88E+07	3.25E+07	4.14E+07	4.14E+07
Harvest, energy content (J/year)	2.26E+12	3.98E+11	9.31E+11	3.21E+12	3.21E+12	1.85E+12	2.08E+12	2.49E+12	2.49E+12

Note 1. L.L. = Lebanese Lira.

efficient and sustainable use of natural resources.

The MFA method provides an estimation of the cumulative (direct + indirect) demand of material resources supporting the generation of a product or service over its lifecycle. The material inputs accounted for are usually divided into four different categories: (1) abiotic raw materials, (2) biotic raw materials, (3) air, and (4) water.

Input flows to the investigated process are converted into material equivalents, multiplying the raw amounts by suitable material intensity (MIT) factors, expressed as gram per unit of input. Then, material flows can be summed to calculate the cumulative material demand for each compartment (abiotic and biotic materials, water, and air), providing a quantitative measure of the environmental burden in terms of material resources consumption.

In this study, the categories abiotic material and water demand were accounted for and the relative MIT factors were selected from the MFA database of the Wuppertal Institute (2011).

2.3.2. Gross energy requirement

The Gross Energy Requirement (GER) method aims at assessing the amount of fossil energy required directly and indirectly to produce a specific good or service (Franzese et al., 2009; IFIAS, 1974). More specifically, the GER method takes into account for electricity, fuels, pesticides, fertilizers and other chemicals, machinery and assets supplied to a process in terms of direct and indirect fossil energy required to produce and make them available to the process.

The GER of each input to a process is calculated multiplying the raw amount by its specific energy intensity factor expressed as Joule or gram of equivalent oil per unit of input. The total GER of the investigated process is calculated as the sum of the GER values of all the inputs used by the process.

Quantifying the cumulative fossil energy used in a process allows an estimation of the total amount of primary energy use, showing to which extent the depletion of non-renewable energy resources is caused by the same process.

2.3.3. Emergy accounting

Emergy accounting is a measure of the cumulative environmental support to a process (Brown and Ulgiati, 2004; Odum, 1996). In particular, the method aims at evaluating the environmental performance of a system on the global scale of biosphere by taking into account the use of free environmental inputs (i.e., solar radiation, wind, rain, and geothermal flow), human-driven material and energy flows, and the indirect environmental support embodied in human labour and services (Franzese et al., 2014).

Emergy accounting is based on two main concepts: solar emergy and unit emergy value (UEV). Solar emergy is defined as the amount of solar energy that is directly and indirectly used up to make a service or product (Odum, 1996). Its unit is the solar emjoule (sej).

The UEV is the solar emergy required to make one unit of a service or product and it is usually expressed as sej J^{-1}, sej g^{-1} or sej $\$^{-1}$ (Odum, 1996).

Inputs to a process are converted into emergy equivalents multiplying the raw amounts by their specific UEVs. Once all inputs are converted into solar emergy, they can be summed to calculate the total emergy use reflecting the cumulative environmental support to a process. Finally, the UEV of the generated product can be calculated dividing the total emergy use by the energy or mass of the total production output.

The UEVs used in this study were updated to the $1.20 \cdot 10^{25}$ sej yr^{-1} biosphere emergy baseline calculated by Brown et al. (2016).

2.3.4. Emissions accounting and impact categories

Downstream environmental impacts are connected with the release of water-borne and air-borne emissions and the production of solid wastes. Each process generates different kinds of emissions that are likely to cause impacts on the environment (Buonocore et al., 2012).

In this study, both local and global emissions were accounted for. Local emissions are generated by the direct combustion of fuel in agricultural machineries while global emissions are due to the indirect energy use for producing and making available systems' inputs (e.g., fertilizers, pesticides, and machineries).

Both local and global emissions were characterized by using the CML method to assess the potential contribution of the investigated agricultural systems to selected environmental impact categories: 1) Global Warming Potential (GWP), expressed as grams of CO_2 equivalent, 2) Eutrophication Potential (EP), expressed as grams of PO_4 equivalent, 3) Acidification Potential (AP), expressed as grams of SO_2 equivalent, 4) Human Toxicity (HT), expressed as grams of 1,4-dichlorobenzene (1,4-DCB) equivalent, and 5) Photochemical Oxidation (PO), expressed as grams of ethylene equivalent. The contribution to each impact category was calculated multiplying the emissions by their specific characterization factors.

3. Results

Fig. 1 shows the system diagram drawn to model the agricultural production system of Lebanon according to a standardized systems language (Odum, 1994, 1996). The diagram shows the system boundary, the main external driving forces (i.e., natural and human-driven flows converging to the agricultural system), the main components and their interactions, and the generated outputs.

This symbolic model represents a first qualitative step useful to set up the quantitative environmental accounting of the input flows supporting the agricultural production at local and national level.

Table 3 summarizes intensive indicators calculated on an annual basis per hectare of the nine investigated crops, showing their performance in terms of environmental costs and impacts.

The emergy density resulted higher for tomato ($8.00 \cdot 10^{16}$ sej $ha^{-1}yr^{-1}$), orange ($7.58 \cdot 10^{16}$ sej $ha^{-1}yr^{-1}$), and potato production ($7.35 \cdot 10^{16}$ sej $ha^{-1}yr^{-1}$) while the GER resulted higher for orange ($3.64 \cdot 10^{5}$ MJ $ha^{-1}yr^{-1}$), potato ($2.22E \cdot 10^{5}$ MJ $ha^{-1}yr^{-1}$), and citrus production ($2.20 \cdot 10^{5}$ MJ $ha^{-1}yr^{-1}$). Similarly, orange, citrus, and tomato production showed higher abiotic material and water demand compared to the other crops (Table 3).

In terms of emissions and contribution to impact categories, orange, potato, and citrus production showed higher values than the other crops. The contribution to GWP ranges from $4.58 \cdot 10^{6}$ g CO_2 eq $ha^{-1}yr^{-1}$ for olive to $2.80 \cdot 10^{7}$ g CO_2 eq $ha^{-1}yr^{-1}$ for orange. Similarly, the AP values range from $1.55 \cdot 10^{4}$ g SO_2 eq $ha^{-1}yr^{-1}$ for olive to $1.25 \cdot 10^{5}$ g SO_2 eq $ha^{-1}yr^{-1}$ for orange (Table 3).

For a better comparison among the investigated crops, intensive indicators were normalized and plotted through a radar diagram (Fig. 2). The size of the area represents a measure of the overall environmental costs and impacts associated to each crop. The smaller this area, the better is the overall environmental performance.

To assess environmental costs and impacts associated to the whole agricultural production in Lebanon, intensive indicators calculated on an annual basis per hectare of each crop were upscaled to the national level by considering the hectares occupied by each crop within the national boundary (Table 1). Table 4 shows the extensive indicators calculated for the nine main investigated crops showing the total resource consumption and generated impacts due to the whole agricultural production in Lebanon.

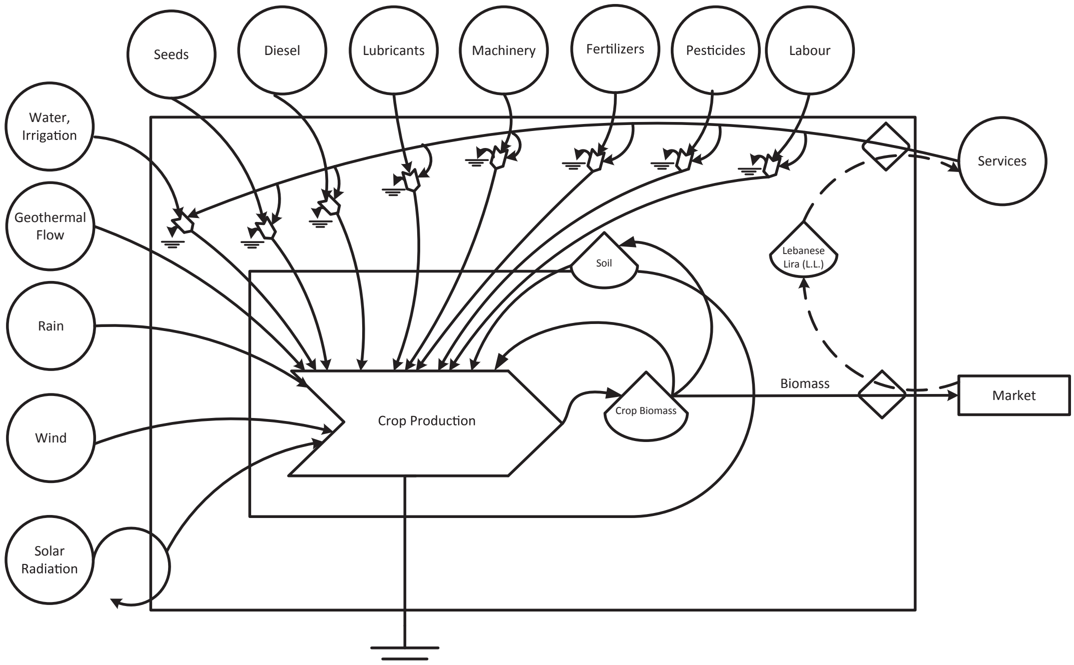


Fig. 1. Agricultural production in Lebanon: system diagram.

Table 3
Intensive indicators calculated per hectare of crop production in Lebanon.

Intensive indicators	Potato	Wheat	Olive	Apple	Citrus	Orange	Cucumber	Tomato	Grape
Emergy Density (sej $ha^{-1}yr^{-1}$)	7.35E+16	1.97E+16	2.26E+16	3.24E+16	4.93E+16	7.58E+16	6.23E+16	8.00E+16	2.83E+16
GER (MJ $ha^{-1}yr^{-1}$)	2.22E+05	7.83E+04	5.44E+04	1.36E+05	2.20E+05	3.64E+05	1.39E+05	1.76E+05	8.41E+04
Water Demand (t $ha^{-1}yr^{-1}$)	6.33E+03	6.76E+02	2.02E+02	2.33E+03	1.45E+04	2.90E+04	7.82E+03	1.02E+04	5.85E+03
Abiotic Material Demand (t $ha^{-1}yr^{-1}$)	1.95E+01	1.31E+01	1.51E+01	1.54E+01	3.34E+01	3.56E+01	2.15E+01	2.33E+01	8.67E+00
GWP (g CO_2 eq $ha^{-1}yr^{-1}$)	1.74E+07	6.41E+06	4.58E+06	1.05E+07	1.72E+07	2.80E+07	1.10E+07	1.38E+07	6.81E+06
AP (g SO_2 eq $ha^{-1}yr^{-1}$)	7.08E+04	2.25E+04	1.55E+04	5.35E+04	7.06E+04	1.25E+05	4.46E+04	6.15E+04	2.70E+04
HT (g 1,4-DCB eq $ha^{-1}yr^{-1}$)	8.47E+04	2.33E+04	1.58E+04	7.94E+04	8.51E+04	1.63E+05	5.40E+04	8.15E+04	2.70E+04

The total emergy supporting the agricultural production in Lebanon resulted $5.46 \cdot 10^{21}$sej yr^{-1}, while the total GER was $1.81 \cdot 10^{10}$ MJ yr^{-1}. The total water and abiotic demand resulted $6.27 \cdot 10^{8}$ t yr^{-1} and $2.64 \cdot 10^{6}$ t yr^{-1}, respectively. The total contribution to GWP resulted $1.45 \cdot 10^{12}$g CO_2 eq yr^{-1} (Table 4).

In addition, extensive indicators calculated for the different crops were normalized and plotted through a radar graph allowing a better comparison among the investigated crops at national level (Fig. 3).

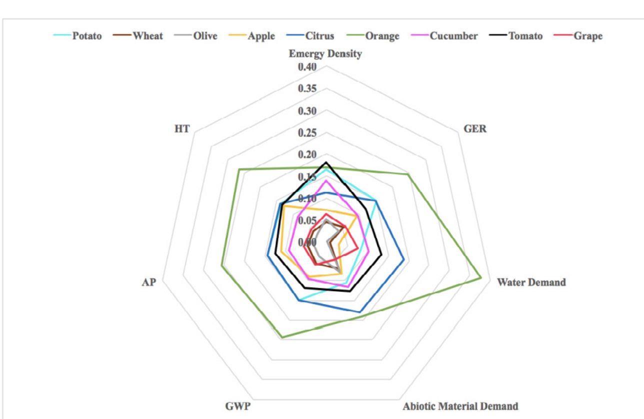


Fig. 2. Comparison among the nine investigated crops (indicators normalized from Table 3).

4. Discussion

The environmental accounting framework implemented in this study resulted a useful tool for exploring environmental costs and impacts due to agricultural production in Lebanon at both local and national level. The multicriteria perspective allowed the assessment of the environmental performance and sustainability of Lebanese agricultural systems from different viewpoints: (a) fossil fuel consumption, (b) abiotic material demand, (c) water demand, (d) environmental support (i.e., emergy demand), and (e) generated emissions and their contribution to impact categories.

Intensive indicators, calculated per hectare of each crop, showed that orange production is characterized by the worst environmental performance, while olive production resulted the best crop in terms of both environmental costs and impacts. As orange production showed the lowest environmental performance, it was further investigated by assessing the contribution of each input to the calculated indicators of environmental cost and impact (Fig. 4). The main inputs negatively affecting the environmental performance were the use of water, diesel, and fertilizers. In addition, the emergy accounting showed that labour and services also represent

Table 4
Extensive indicators calculated for the nine investigated crops at national level.

Extensive indicators	Potato	Wheat	Olive	Apple	Citrus	Orange	Cucumber	Tomato	Grape	Total
Solar Emergy (sej yr^{-1})	1.39E+21	7.86E+20	1.28E+21	3.82E+21	2.91E+20	6.25E+20	1.18E+20	2.48E+20	3.41E+20	5.46E+21
GER (MJ yr^{-1})	4.20E+09	3.12E+09	3.09E+09	1.60E+09	1.30E+09	3.00E+09	2.63E+08	5.46E+08	1.01E+09	1.81E+10
Water Demand (t yr^{-1})	1.20E+08	2.69E+07	1.15E+07	2.75E+07	8.57E+07	2.39E+08	1.48E+07	3.18E+07	7.04E+07	6.27E+08
Abiotic Material Demand (t yr^{-1})	3.69E+05	5.21E+05	8.56E+05	1.82E+05	1.97E+05	2.93E+05	4.08E+04	7.22E+04	1.04E+05	2.64E+06
GWP (g CO_2 yr^{-1})	3.28E+11	2.55E+11	2.60E+11	1.24E+11	1.01E+11	2.31E+11	2.08E+10	4.26E+10	8.18E+10	1.45E+12
AP (g SO_2 yr^{-1})	1.34E+09	8.97E+08	8.80E+08	6.31E+08	4.16E+08	1.03E+09	8.46E+07	1.91E+08	3.24E+08	5.79E+09
HT (g 1,4-DCB eq yr^{-1})	1.60E+09	9.27E+08	8.96E+08	9.37E+08	5.02E+08	1.34E+09	1.02E+08	2.52E+08	3.24E+08	6.88E+09

Fig. 3. Comparison among the nine investigated crops at national level (indicators normalized from Table 4).

a high contribution, accounting for about 42% of the total emergy density.

Olive production showed the best environmental performance. Indeed, olive production in Lebanon is based on environmental friendly practices since it requires a low consumption of mass and energy inputs and labour compared to other crops (Darwish et al., 2004). The water demand for olive cultivation resulted also lower than the other crops (Fig. 2). In fact, the requirement of water for olive irrigation is negligible and only 8% of total olive production in Lebanon is irrigated, while most of the area is rainfed (El Riachy et al., 2017).

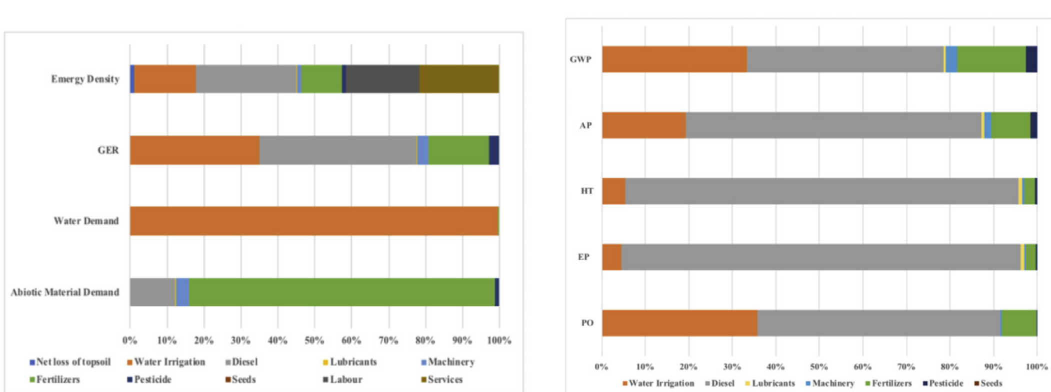
Extensive indicators, calculated at national level, showed higher values (i.e., worse environmental performance) for potato and wheat production compared to the other crops. These indicators were influenced by the production area of the two crops, occupying 12% and 25% of the total investigated agricultural land in Lebanon. Instead, cucumber production, occupying about only 1% of the total agricultural area at national level, showed the best environmental performance both in terms of environmental costs and impacts.

Olive cropping systems occupy 36% of the total agricultural area covered by the nine investigated crops (MOA, 2010). In spite of its large cropped area at national level, the calculated extensive indicators showed lower environmental costs and impacts compared to other crops, confirming the advantages of the environmental friendly practices applied to olive production in Lebanon.

The outcomes of this study can be useful to support farmers and policy makers. Farmers may benefit from the characterization of the investigated agricultural production systems through the calculated intensive indicators. These indicators help identifying the input flows responsible for the largest environmental burdens to be lowered for improving the environmental performance of the cropping systems. Policy makers may be more interested in the analysis of the extensive indicators useful in support of environmental planning, scenario and trade-off analyses.

Since sustainable agriculture is strongly needed to ensure food security in the long run, multicriteria environmental accounting can generate useful information to face the issue of food security from a more comprehensive and interdisciplinary viewpoint. Indeed, the complex issue of food security involves environmental, socio-ethical, and economic aspects (Wambua et al., 2014), all worth of attention to tackle the problem of food insecurity worldwide.

Finally, we propose a set of biophysical and socio-economic indicators for integrating environmental accounting with a socio-economic perspective on food security and sustainable agriculture (Table 5). Biophysical indicators (1–6) are aimed at assessing resource consumption and emissions due to agriculture, and the relationship between agricultural production and soil quality.



(a) (b)

Fig. 4. Orange production: contribution of input flows to calculated indicators of environmental cost (a) and impact (b).

Table 5
Environmental and socio-economic indicators of food security at national level.

Indicator	Amount	Unit
1. Water use	$6.27 \cdot 10^8$	t yr^{-1}
2. Material demand	$2.64 \cdot 10^6$	t yr^{-1}
3. Fossil energy use	$1.81 \cdot 10^{10}$	MJ yr^{-1}
4. Emergy demand	$5.46 \cdot 10^{21}$	sej yr^{-1}
5. GHG emissions	$1.45 \cdot 10^6$	t CO_2 eq. yr^{-1}
6. Soil quality	n.a.	% organic matter
7. Access to food	n.a.	%
8. Jobs in agricultural sector	n.a.	n. yr^{-1}
9. Gender inequality	n.a.	%
10. Public education and awareness	n.a.	%
11. Household food waste	n.a.	t yr^{-1}
12. Food consumption Vs. food need	n.a.	%
13. Malnourished people	n.a.	%

Note 2. n.a. = not accounted in this study.

Socio-economic indicators (7–13) are related to access to good quality food, job creation, gender inequality, the availability of information on health and sanitation, household consumption patterns and undernourishment. This set of multicriteria indicators provides a broad understanding of the complex issue of food security and can help exploring its four broad dimensions: availability, access, utilization, and stability (FAO et al., 2017).

5. Conclusions

Nine main Lebanese agricultural productions were investigated by means of a multicriteria environmental accounting framework. The study allowed the comparison of different cropping systems, investigated at farm and country level. Crops characterized by high environmental costs and impacts (e.g., orange) and environmental friendly crops requiring a smaller support of human-driven flows and labour (e.g., olive) were identified.

The outcomes of this study can support both farmers and policy makers in charge of ensuring the sustainable management of agricultural production while providing access to safe, healthy, and nutritious food for a growing population.

Intensive indicators, calculated at farm level, can be useful to explore the typology and amount of input flows supporting agricultural production systems. This information allows the improvement of agricultural practices through technological fixes and/or alternative management options capable of reducing the consumption of resources (e.g, water, soil, fuels, and chemicals) while improving both the economic and environmental performance of farms.

On the other hand, extensive indicators, calculated at national level, can provide useful information to policy makers in charge of ensuring both long-term food supply and the maintenance of resilient agroecosystems.

In terms of future development, the environmental accounting framework implemented in this study will be integrated with socio-economic evaluations to generate a large set of multicriteria indicators capable of addressing the issue of food security through an interdisciplinary approach.

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