Applied Energy 127 (2014) 115–124

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Carbon footprint of an olive tree grove

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HIGHLIGHTS

- The carbon stocks from olive permanent and non-permanent components were evaluated.
- The emissions due to the cultivation processes of the olive trees were identified.
- The carbon footprint of the olive grove over its life cycle (11 years) was assessed.
- The break-even point (where carbon stocks exceed carbon emissions) was determined.
- Actions for reducing emissions during the olive grove life cycle were proposed.

ARTICLE INFO

Article history:
Received 3 October 2013
Received in revised form 6 March 2014
Accepted 4 April 2014
Available online 3 May 2014

Keywords:
Carbon footprint
Life Cycle Assessment
Olea europaea
Carbon stock
CO_2 sequestration

ABSTRACT

In recent years, the role of Life Cycle Assessment (LCA) of products and processes has increased in importance, since it is the best technique to quantify environmental impacts associated with a process or product.

The study was carried out in an olive grove located in Central Italy with "Leccino" cultivar. The olive grove was established in year 2000 with a planting distance of 5.5 × 5.5 m, trained to the vase system, under dry conditions. The same methodology used for forestry trees ("model tree") was adopted to estimate the biomass and the respective carbon stock of the below-ground and above-ground parts of the olive tree as well as quantification of the non-permanent components periodically removed, i.e. fruits and prunings.

The environmental impacts associated with management processes were evaluated according to LCA standards (UNI EN ISO 14040 and 14044). In relation to the impact on climate change, the CO_2 sources and sinks were calculated in order to obtain the net carbon stock of the olive grove. These data were confirmed by experimental measurement of the tree biomass in three representative olive trees. The treatments and processes that had the greatest impact were identified and the individual phases and materials were then analysed in order to propose possible actions for reducing emissions throughout the entire olive grove life cycle. Removals and emissions were compared on a time scale, in order to identify the break-even point.

The results allow to assess the carbon footprint of an olive grove, at different stages of its life cycle, as a support tool for creating a sustainable production chain in the olive sector. The paper proposes a methodological approach that can be adopted also in other olive groves with different horticultural management models.

1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) signed in Rio de Janeiro in 1992 was the first international legally binding tool directly related to climate change. With the Kyoto Protocol, the regulatory approach based on economic elements became an integral part of the strategy for reducing climate-changing emissions (Joint Implementation, Clean Development mechanism and Emissions Trading) [1]. Through specified, binding and quantifiable targets of the Protocol, industrialized and in-transition countries are committed to limiting their greenhouse gas (GHG) emissions derived from human activities.

To reduce GHG emissions, and specifically to fix CO_2, the Protocol identifies a number of activities that are closely related to land use (Land Use, Land-Use Change and Forestry, LULUCF). In this

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http://dx.doi.org/10.1016/j.apenergy.2014.04.019
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sector GHG sources and sinks are considered in five categories: forest land, cropland, grassland, wetlands and settlements. In 2006, with the Guidelines for national greenhouse gas inventories, the Inter-governmental Panel on Climate Change (IPCC) merged the Agricultural and LULUCF activities into a single category called Agriculture, Forestry and Land Uses (AFOLU).

In this category, greenhouse gases have a twofold sign: estimates should include both CO_2 absorption (live biomass, dead biomass and soil) and emissions. This mechanism is characterized by a series of complex biological, physical and chemical processes that are widespread and highly variable over time. The factors affecting emissions and removals can be both natural and anthropogenic.

Through photosynthesis, plants absorb CO_2 from the atmosphere and release O_2. A portion of the absorbed CO_2 is returned to the atmosphere through respiration, while a part is stored in various organic compounds. This CO_2 component increases, creating a so-called *carbon sink*, until it reaches the upper limit beyond which the losses, due to respiration and the death of the trees, offset the increase in carbon due to photosynthesis. It should be noted that on a worldwide scale, after the use of fossil fuels for energy, agriculture and livestock are the major causes of greenhouse gas emissions (in particular CH_4 and N_2O). These net GHG emissions plus the deforestation and degradation of tropical forests are responsible for at least 15% of greenhouse gas emissions [2].

While quantification of the amount of forest carbon has been the object of extensive studies [3–6], information about the amount from agricultural systems is extremely limited, because their productive role is usually considered rather than their ecological role.

1.1. Life Cycle Assessment and carbon footprint

Life Cycle Assessment (LCA) is an objective procedure for evaluating energy and environmental loads related to a process or activity. It is carried out by identifying the energy and materials used and the waste released into the environment. In an assessment, the entire life cycle of the process or activity is evaluated, including the extraction and processing of raw materials, manufacturing, transport, distribution, use, reuse, recycling and final disposal. The International Standards Organization (ISO) has defined and adopted standards that provide references for the correct application of a LCA, the UNI EN ISO 14040: 2006 [7] and UNI EN ISO 14044: 2006 [8]. They are within the scope of the ISO 14000, related to environmental management systems and instruments for their implementation.

In an LCA there is a shift from a separate study of the individual elements in the production processes, to a comprehensive view, where all the processes of transformation are considered in order to achieve a specific final function. It starts from the extraction of the raw materials and ends with end-of-life disposal ("cradle-to-grave", while aiming at the highest degree of environmental sustainability, i.e. "cradle-to-cradle" through reuse/recycling). The application of LCA methodology does not guarantee a reduction of emissions or energy consumption, but it highlights the "weak points" of the production process and identifies possible improvements in technology and management within a perspective of sustainable development [9]. At the European level, the strategic importance of LCA as a scientific tool for identifying significant environmental aspects is clearly expressed in the Green Paper COM 2001/68/CE and COM 2003/302/CE related to Integrated Policy of Products, and it is indirectly supported by European Regulations: EMAS (1221/2009/CE) and Ecolabel (66/2010/CE).

The Carbon Footprint (CF) can be seen as an LCA limited to the emissions that have an effect on climate change. It is defined as the sum of GHG emissions and removals, expressed as the net impact on global warming in terms of CO_2 equivalents; the Carbon Footprint of a Product (CFP) is specifically the CF of a product system and the GHG emissions refer to its complete life cycle. The GHG emissions that are specified by the Kyoto Protocol include, among others, carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) [10]. The Global Warming Potential (GWP) is an indicator that quantifies the carbon footprint. This factor describes the radiation forcing impact of one mass-based unit of a given greenhouse gas related to an equivalent unit of carbon dioxide over the given period of time of 100 years (GWP100). GWP is thus based on a relative scale which compares the specific GHG with an equivalent mass of CO_2, whose GWP by definition is equal to 1. Updated GWP factors from the IPCC should be used to quantify the amount of $CO_{2\text{-eq}}$. The GWPs for different emissions can then be added together and the sum expresses the overall contribution of these emissions to climate change [11]. Although based on a life cycle approach, carbon footprints only address impacts on climate change. In order to avoid misleading results and erroneous strategic decisions, a CF assessment should be extended to include other important environmental impacts, which often run opposite to climate change resulting in a "shifting of burdens".

Many researchers have analysed the carbon footprint of *systems and processes*. Some examples are: strategies for integrating waste and renewable energy into the energy source mix and consequently for reducing the carbon footprint of locally integrated energy sectors [12]; a collaborative web service framework for measuring, monitoring, and integrating environmental and carbon footprint data in construction supply chains [13]; a comparison in terms of cost and carbon footprint of two potential water supply options, seawater desalination and water conveyance from remote locations [14]; an analysis of carbon footprint within the context of automobile supply chain management [15]; and an evaluation of the environmental impact, and therefore the actual sustainability of photovoltaic technology, examining a ground-mounted plant (1.7 MW_e) [16].

With reference to *products* and not to processes, the CFs of various types of shopping bags (plastic, paper, non-woven and woven) were evaluated using LCA in cradle-to-gate and cradle-to-grave scenarios [17]. Other studies have been carried out addressing: a comparison between electric and LPG forklifts [18]; the uncertainty in estimated CFs of a liquid and a compact powder detergent and how the uncertainty varies with the type of comparison [19]; the life cycle carbon footprint of National Geographic magazine, the results of which provided the publisher and material suppliers with information for reducing GHG [20]; a Life Cycle Energy Analysis (LCEA) of two tourist accommodation facilities in Poole, Dorset (UK) to quantify their CO_2 emissions [21]; the construction sector (materials, technical elements and entire building) [22–26].

With regard to *food products*, the scientific literature shows that LCA and CF studies have been carried out in different sectors. Several consumer goods have been investigated in order to estimate: for example, the carbon footprint of bread produced and consumed in the UK [27]; sugar produced in eastern Thailand [28]; butter and dairy-blend products with the focus on fat content and size and type of packaging [29]; carbon fluxes in the biomass of two typical Mediterranean orchards (olives and peach) [30]. Calculating the CF of food products is complex and is associated with unavoidable uncertainty due to the inherent variability of natural processes. Some researchers have quantified the uncertainty of common food products, such as King Edward table potatoes grown in the Östergötland region of Sweden or a refined wheat-based product (pasta) for different resolutions of farm-level in-data [31,32]. Finally an interesting assessment was carried out on the effects that individual consumption behaviour has on climate change, focusing on products that satisfy the same need but which have