Environmental footprint of using renewable energies

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Abstract. Daily human activities have beside desired effects on the quality of life of human beings, also unwanted ones, especially regarding environmental pollution. Pollutants emissions are rapidly increasing, especially the emissions of carbon dioxide. The major part of the needed energy in human daily life is currently obtained on the basis of burning fossil fuels. Because of the pretty short life time of fossil fuels, governments are currently keen to move to using renewable energies. On the other side, as industrial activities are steadily developing, the concern over their potential negative environmental impacts is growing too. Environmental impact assessments are carried out by using several tools. A currently pretty used one is connected to the environmental footprint account of different products or processes. It actually measures the pollutants emissions because of resources demand in the context of diverse production or consumption processes. Although renewable energy provides substantial benefits for our climate, health and economy, it is important to evaluate the environmental impact of the corresponding technologies connected to their usage. In this context, the environmental footprint of using renewable energies is debated by calculating the corresponding CO_2 emissions. Decreasing possible environmental impact of using renewable energies, technical but especially organizational measures are required.
Key Words: environmental footprint, pollutants emissions, renewable energies, life cycle assessment.

Introduction. Earth is the only planet from the solar system and probably among the few planets in which the physic-chemical and energetic factors have compatible values with the forms of life that we can nowadays conceive. The last developments registered in technological and socio-economic fields over the past decades have highlighted the issue regarding the finite nature and instability of Earth's natural resources, especially of fossil fuel supply. Therefore, more and more questions regarding the proper management of these resources in line with providing the necessary elements for the planet's population have begun to constantly emerge.

Different topics from the area of major phenomena regarding environmental quality deterioration by environmental pollution have been debated by different specialists with increasing responsibility starting with the first report to Club of Rome (Meadows et al 1972). Discussions took place regarding global problems, as world population growth, increase of energy and natural resources consumption and environmental pollution, as presented in Figure 1. A lot of debates have taken place on different levels in order to recognise the best strategies on how to overcome the created conflict situation. Several attempts on global level have been registered for delivering a worldwide applicable solution (Grunwald 2002; Jischa 2005). Finally, in 1987 the concept of sustainable development was defined in the Brundtland Report of the World Council on Environment and Development (Hauff 1987). Pretty fast this concept was accepted as being the most suitable solution for the created complex global ecological, economic and social problems (Jischa 2005). The idea of sustainable development was very much discussed during the Conference for Environment and Development in Rio de Janeiro (1992), that ended by adopting the closing document "Agenda 21" (Agenda 21). Debates have followed since then with different occasions, a considerable number of forecasts and scenarios being developed for a variable duration perspective, just to give the possibility to think about potential future developments (Tulbure 2003; Jischa 2005).

As sustainable development has worldwide been accepted as being the viable solution for the future world development, not the same situation has been remarked concerning existing possibilities for concretely applying the concept depending on the analysed regions, i.e. regarding his operationalisation possibilities (Jischa 2005). The operationalisation of the concept of sustainable development means the translation of its objectives into political measures and controlling instruments.

A general methodology in order to concretely apply sustainable development on regional and local level is consisting of different phases (Tulbure 2003). Going into details there is a need to start with the definition of the regional problem, followed by specifying the space and time scales. Further there is a need to approach the region in a systemic way by analyzing and modeling the most important interactions and to establish concrete aims, depending on the followed goals in the observed region, especially by assessing potential environmental impacts of different technological applications, as presented in Figure 1. Regarding the debates about growth of energy consumption and environmental pollution, renewable energy resources are gaining an important role, as emphasized in Figure 1 (Kaltschmitt et al 2014).

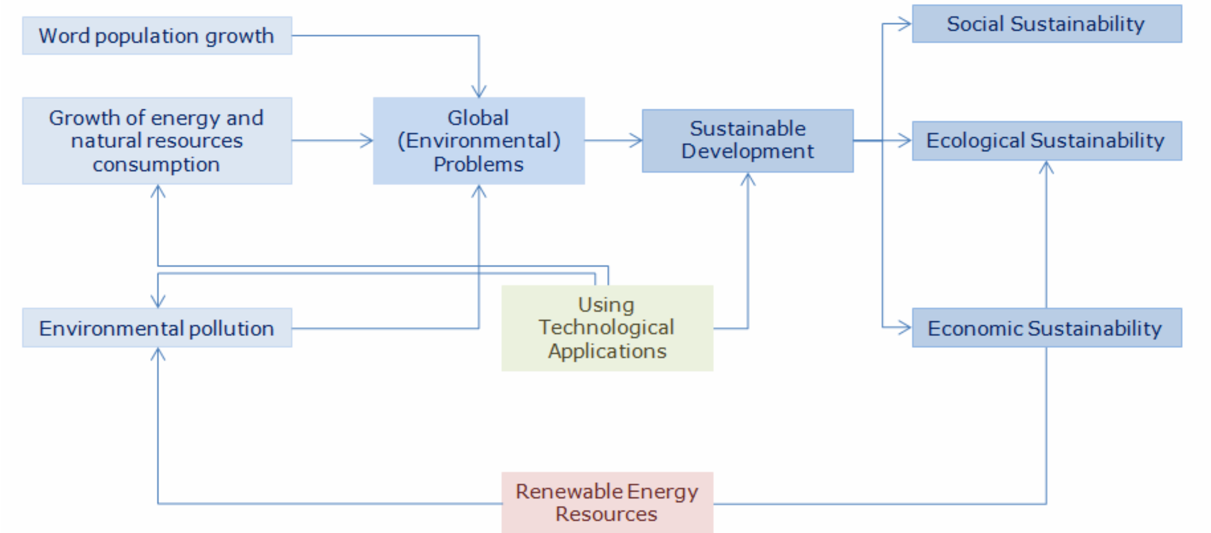

Figure 1. Technological applications for assuring sustainable development as response to the global problems.

It is known that each resource of Earth has an *Environmental Footprint* that is smaller or bigger. The vision should be concentrated on using the Earth resources having the smallest environmental footprint so that in the end the most efficient life cycle of a product or of an activity could be obtained and the minimum impact on the environment (Jischa 2005). Using renewable energy resources could be the intended aim in the sustainability direction. Depending on the level of the technological development in the considered region, often technological applications are permitting to use renewable energy resources, being a possible solution to get sustainability, as shown in Figure 1. Possible results to be got after concretely applying the proposed measures have anyway to be analyzed, in this context it is relevant to assess environmental impacts of using renewable energy resources (Grunwald 2002). This can be made by environmental footprint account of using renewable energies when developing different scenarios based on system modelling and thereafter comparing these scenarios when using renewable energy resources (Kaltschmitt et al 2014). When all these steps are clarified, then the developed concept can be applied into the practice on regional or local level for assuring the most efficient use of renewable energy resources in the considered region.

Material and Method. Life Cycle Assessment (LCA) of a product represents a tool for environmental management where materials, energy and waste flows of the product are identified over its life cycle, together with their impacts on environment (Jischa 2005).

The LCA is an analysis which registers all the effects on environment of a product during its life, from the production to the consumption and recycling. The general life cycle of a product is presented in Figure 2 (Tulbure 2013). It can be observed that besides production and consumption processes also transport processes, stated with ”T”, are taken into account. LCA is appropriate to improve the production lines of products, to compare different products and to ecologically optimise the life-cycle of products.

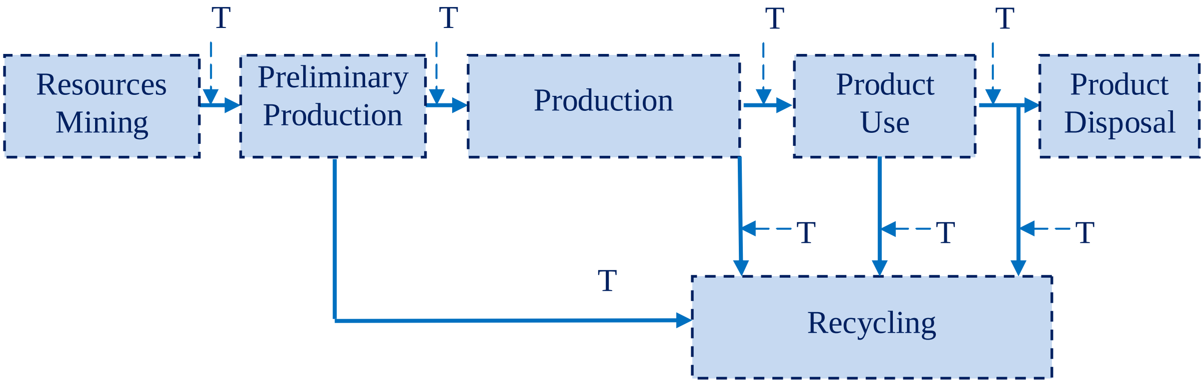

Figure 2. General life cycle of a product.

The LCA is in fact an ecobalance which can be performed as a singular study or as a comparative study. It registers material and energetical flows when producing something, or within a process or a company. Such an analysis has several steps (Tulbure 2013): definition of goal and scope; inventory analysis; impact assessment; interpretation of results.

a) Definition of goal and scope - The goal shall clearly state the intended application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated. In defining the scope of an LCA study, the following items shall be considered and clearly described: the functions of the product, the functional unit, the system boundaries, methodology of impact assessment, data requirements, assumptions, limitations.

b) Inventory analysis – This phase involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources and also pollutants emissions by the system.

c) Impact assessment - It is aimed at evaluating the potential environmental impacts using the results of the inventory analyses. The impact assessment may include elements as assigning of inventory data to impact categories, and possibly aggregating the results. It is to be mentioned that the methodological and scientific framework for impact assessment is still being developed (Tulbure 2013). Very often in this step aggregated indicators are used for allowing a transparent evaluation.

d) Interpretation of results - in this phase the findings from the inventory analysis and the impact assessment are combined together. The interpretation should take the form of conclusions and recommendations to decision-makers.

With respect to LCA a difficult step is represented by getting on data and information about products and production processes (Jischa 2005). To compare different life cycle stations of a product from the point of view of pollutants emissions there is a need to use different environmental indicators. This process is still in development (Tulbure 2013). The life cycle of a product takes into account relevant steps in the existence and use of a product, as shown in Figure 2, starting with the extraction of mineral resources used to manufacture the product and ending with the disposal of the product (Grunwald 2002):

- resources mining: this phase refers to the extraction of mineral resources, that will become the raw material used to manufacture the respective product;
- preliminary production: this phase includes the manufacture of components that will be assembled during production to get the desired final product;
- production: in this phase the components are assembled, resulting the product in its final form;
- product use: after the sale of the product, it enters in the stage of use;

- product disposal: in this phase the used product is directed to the phase of reuse or recycling and waste processing.

The environmental footprint is actually expressing the pollutants emissions because of resources demand based on diverse consumption processes happening in our daily life. Although renewable energies, as wind, solar, geothermal, hydroelectric, are considered environmental friendly, when considering their whole life-cycle, it can happen that certain environmental impacts can be recognized (Kaltschmitt et al 2014).

Our daily human activities have beside positive impacts also unwanted effects by pollutants emissions, especially of carbon dioxide. The major part of needed energy in the human daily life is obtained on the basis of burning fossil fuels. Because of their pretty short life time, governments are currently keen to move to using renewable energies. On the other side, as industrial activities grow, the concern over their negative environmental impacts grows too. Regarding environmental impact assessment there are several tools used in this regard. An interesting one is connected to the calculation of the environmental footprint of different products or processes. It actually measures the pollutants emissions because of resources demand based on diverse consumption processes happening in our daily life. Although renewable energy, as wind, solar, geothermal, hydro-electric and biomass, provides substantial benefits for our climate, our health and our economy, it is relevant to evaluate the environmental impact of the technologies used for transforming these renewable energies in electric and thermal energy necessary for our daily activities. The pollutants emissions in the life cycle of renewable energies, especially CO_2 emissions, will be calculated, concluding in this way the environmental footprint of using renewable energies.

Results and Discussion. In the renewable energy field, a photovoltaic panel has been chosen in order to evaluate its environmental impact. When considering the whole life-cycle of the product, as presented in Figure 2, due to the fact that in the phase of Product Use, a photovoltaic panel does not produce any emissions, in the following the phase of Production will be considered.

The approached scenario is considering that the main components which are needed for the photovoltaic panel manufacturing, especially the solar cells, are brought from Germany and the assembly part is made in Romania, being necessary different main components for the photovoltaic panel manufacturing. For this it is important to consider the CO_2 emissions resulted from the transport of raw materials (Table 1), taking into account the following aspects: distance between countries: 1600 km; means of transport: truck; used fuel: diesel; truck average consumption: 33 L/100 km; fuel density: ρ = 825 kg/m^3 (15ºC); Carbon percentage present in fuel: C_C = 75% (Tulbure 2013).

Table 1

CO_2 emissions resulted from raw materials (the components) transport

Total fuel volume consumed [L]	*Total fuel quantity consumed [kg]*	*Amount of C in fuel [kg]*	*CO_2 emissions [kg]*
528	435.6	326.7	1197.9

Further, the energy consumption needed for the operational equipments has been calculated, given in Table 2, knowing their power and operating time (Altius 2016). The machines are:

- a photovoltaic cell attachment machine (U1);
- a laminator (U2);
- a panel frame trimmer (U3);
- a test equipment (U4).

Moreover, in order to determine the CO_2 emissions resulted from the use of all four machines, it has been considered that the electrical energy is obtained 100% from coal-fired plants (the carbon content in coal is considered 75% C). Knowing the heat value of coal as being 23 MJ/kg at a net efficiency of 32% of the thermoelectric power plant (Tulbure 2013), the amount of coal needed to produce a photovoltaic panel has been determined.

Table 2

Electrical energy consumption regarding the assembly of the specified machines

Machine	*Machine power [kW]*	*Operating time [s]*	*Electrical energy consumption [MJ]*
U1	6	120	0.72
U2	27	240	64.8
U3	5	300	1.5
U4	3	600	1.8
	Total energy consumption		68.82

The amount of the needed thermal energy for getting the corresponding electrical energy for the above mentioned machines has been obtained dividing the amount of the calculated electrical energy by the net efficiency of the power plant, results given in Table 3.

Table 3

The amount of thermal energy consumed for a solar panel production

Machine	*Thermal energy [MJ]*
U1	2.25
U2	202.5
U3	4.68
U4	5.62
Total	215.05

In order to calculate the carbon quantity from the burned coal mass used in the thermoelectric power plant, the mass of coal (m_{coal}) has been calculated, which contains 75% C and it represents the efficiency of thermal energy to the heat value of coal. Moreover, giving the fact that the coal contains about 75% C, the carbon quantity (m_C) in the coal mass has been calculated and in the end, considering the chemical reaction of CO_2: $C + O_2 \rightarrow CO_2$, the CO_2 emissions when burning the respective coal quantity have been determined (Table 4).

Table 4

CO_2 emissions of a solar panel production

Machine	m_{coal} *[kg]*	m_C *[kg]*	E_{CO_2} *[kg]*
U1	0.09	0.06	0.24
U2	8.80	6.60	24.20
U3	0.20	0.15	0.55
U4	0.24	0.18	0.67
		Total	25.66

It results that the total quantity of CO_2 emissions for a solar panel, including the phase of components transport and of panel production, is 1197.9 + 25.6 = 1223.5 kg CO_2.

Conclusions. The operationalisation of the concept of sustainable development means to try to find the balance among technical, economic, environmental and social aspects. Giving emphasis to technical and environmental aspects the presented tool, LCA, is represented by establishing the environmental footprint of different products or processes for environmental assessments. Each resource of Earth has an environmental footprint that is smaller or bigger. The vision should be concentrated on using the Earth resources having the smallest environmental footprint so that in the end it could be obtained the most efficient life cycle of a product or of an activity and the minimum impact on the environment. In this regard an assessment method based on an emission indicator has been presented and applied for a photovoltaic panel in the field of using renewable energy resources. As a result of the calculation, the CO_2 emissions for the transport of the solar panel components and for the production itself are about 1.2 tons and do not exist in the photovoltaic panel use phase, which is the most important phase in the life cycle of a product. This result emphasises the significance of the presented method, because it is possible to compare environmental impacts of using different energy resources by calculating the CO_2 emissions over the whole life-cycle or only in the utilisation phase of each of these. The made calculations are emphasising that for the photovoltaic panel the transport phases are considerably increasing the environmental footprint. This means that using renewable energies could be connected with a high amount of pollutants emissions i.e. with a considerable environmental footprint. Several measures could be considered to reduce these impacts, especially technical measures for reducing the emissions in the production phase of the panel, but also organizational measures regarding the corresponding transport phases. It would be relevant to consider possibilities regarding reducing the transport distances of the panel components to use other transport means, as train, for instance for big distances. Anyway in future works would be interesting to calculate the necessary usage time of photovoltaic panels so that the CO_2 emissions would be neutralized because of the electricity production in an environmental friendly way.

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