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ANALYSIS

The water footprint of energy from biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply

P.W. Gerbens-Leenes, A.Y. Hoekstra, Th. van der Meer*

University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

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ABSTRACT

This paper assesses the water footprint (WF) of different primary energy carriers derived from biomass expressed as the amount of water consumed to produce a unit of energy (m^3/GJ). The paper observes large differences among the WFs for specific types of primary bio-energy carriers. The WF depends on crop type, agricultural production system and climate. The WF of average bio-energy carriers grown in the Netherlands is 24 m^3/GJ, in the US 58 m^3/GJ, in Brazil 61 m^3/GJ, and in Zimbabwe 143 m^3/GJ. The WF of bio-energy is much larger than the WF of fossil energy. For the fossil energy carriers, the WF increases in the following order: uranium (0.1 m^3/GJ), natural gas (0.1 m^3/GJ), coal (0.2 m^3/GJ), and finally crude oil (1.1 m^3/GJ). Renewable energy carriers show large differences in their WF. The WF for wind energy is negligible, for solar thermal energy 0.3 m^3/GJ, but for hydropower 22 m^3/GJ. Based on the average per capita energy use in western societies (100 GJ/capita/year), a mix from coal, crude oil, natural gas and uranium requires about 35 m^3/capita/year. If the same amount of energy is generated through the growth of biomass in a high productive agricultural system, as applied in the Netherlands, the WF is 2420 m^3. The WF of biomass is 70 to 400 times larger than the WF of the other primary energy carriers (excluding hydropower). The trend towards larger energy use in combination with an increasing contribution of energy from biomass will enlarge the need for fresh water. This causes competition with other claims, such as water for food.

1. Introduction

Fresh water is a prerequisite for life on earth. It is an essential natural resource for basic human needs such as food, drinking water and a healthy environment. In the coming decades, humanity will face important challenges, not only to meet these basic human needs but also to ensure that the extraction of water from rivers, streams, lakes and aquifers does not affect freshwater ecosystems to perform their ecological functions (Postel, 2000). Today, humanity already uses 26% of the total terrestrial evapotranspiration and 54% of accessible runoff (Postel et al., 1996). For a world population of 9.2 billion, as projected by the United Nations for 2050 (United Nations, 2007), there are reasons for profound concern in several regions and countries with limited water resources about whether food and fibre needs of future generations can be met (Fischer et al., 2001; Postel, 2000; Rockström et al., 2007; Vörösmarty et al., 2000).

The scientific as well as the international political community consider global change often in relation to climate

* Corresponding author.
E-mail address: p.w.gerbens-leenes@utwente.nl (P.W. Gerbens-Leenes).

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change. It is generally accepted that emissions of greenhouse gasses, such as CO_2 from fossil energy carriers, are responsible for anthropogenic impacts on the climate system. A shift towards energy carriers that are supposedly CO_2-neutral, such as biomass, is heavily promoted. Other advantages of these renewable energy sources are an increase in energy supply security, resource diversification, and the absence of depletion risks (Vries et al., 2006). There are three categories of biomass for energy: (i) food crops, (ii) energy crops, and (iii) organic wastes (Minnesma and Hisschemöller, 2003). Food crops that are used for energy are, for example, sugar cane, providing ethanol, and rapeseed, providing biodiesel; typical energy crops are poplar and miscanthus, providing heat. The variety in organic wastes is enormous. Wastes are generated in agriculture (e.g. manure), industry or households.

Nowadays, the production of biomass for food and fibre in agriculture requires about 86% of the worldwide freshwater use (Hoekstra and Chapagain, 2007). In many parts of the world, the use of water for agriculture competes with other uses such as urban supply and industrial activities (Falkenmark, 1989), while the aquatic environment shows signs of degradation and decline (Postel et al., 1996). An increase of demand for food in combination with a shift from fossil energy towards energy from biomass puts additional pressure on freshwater resources. For the future, hardly any new land is available, so all production must come from the natural resource base currently available (FAO, 2003), requiring a process of sustainable intensification by increasing the efficiency of the use of land and water (Fresco, 2006).

A tool that has been developed for the calculation of water needs for consumer products is the concept of the water footprint (WF). This tool has been introduced by Hoekstra and Hung (2002) and has been developed further by Hoekstra and Chapagain (2007, 2008). Those authors define the WF as the total annual volume of fresh water used to produce the goods and services related to consumption. So far, the tool has been used to assess the WF of food and cotton consumption. The objective of this study is to assess the water footprint per unit of energy from biomass (in m^3/GJ) and to compare this with the WF of other primary energy carriers (oil, coal, gas, uranium, wind, solar energy and hydropower). In addition, the study aims to estimate how much additional fresh water is needed if a shift occurs towards energy from biomass and how this relates to the water needs for food and fibres.

2. Method

2.1. Primary energy carriers

Energy exists in many forms, such as kinetic energy, chemical energy, electricity or heat. Among these various forms, conversions occur. Biological photosynthesis, for example, converts solar photonic energy into chemical energy forming biomass. Many substances such as food or plastics contain energy (Verkerk et al., 1986). In energy analysis, however, a substance is considered an *energy carrier* if the substance is predominantly used as a source of energy (Blok, 2006). Before energy is available in an applicable form for human utilization, for example, for warming a house, cooking or lighting, energy passes a number of stages in a supply chain (Blok, 2006). Energy carriers derive from energy sources, including both non-renewable and renewable sources. Primary energy carriers are defined as carriers directly derived from a natural source without any conversion process, while secondary energy carriers are the product of a conversion process (Blok, 2006).

Throughout history, humans have used renewable energy from biomass, for example wood for heating and cooking. The FAO (2006) defines biomass as material of organic origin, in non-fossilized form, such as agricultural crops and forestry products, agricultural and forestry wastes and by-products, manure, microbial biomass, and industrial and household waste. Biomass is applied for food (e.g. wheat), materials (e.g. cotton), or for energy (e.g. poplar). At present, biomass is the most important renewable primary energy carrier (Blok, 2006). Biomass is often converted into *biofuels,* renewable secondary energy carriers in solid, liquid or gaseous form. Examples are charcoal, ethanol, biodiesel, and biogas (Minnesma and Hisschemöller, 2003; Blok, 2006). The energy derived from these fuels is termed *bio-energy*.

2.2. Biomass

Biomass is an umbrella term for all the material flows that derive from the biosphere, such as food and feed crops, energy crops, and organic wastes, such as manure and crop residues. For the production of biomass, agriculture applies the natural land base, requiring the input of fresh water for crop growth. For the assessment of the water footprint of biomass, this study only took crops into account; wastes fell outside the scope of the study. In general, agriculture grows crops for their reproductive or storage organs that have an economic value when applied for food, feed or materials production. The harvested organs are termed crop yield, i.e. the harvested production per unit of harvested area for crop products (FAO, 2007). The growth of these organs requires the preceding growth of complete plants with stems and foliage, however (Gerbens-Leenes and Nonhebel, 2004). The ratio of the crop yield to the total biomass yield is termed the harvest index (HI) and shows large differences among crops (Goudriaan et al., 2001). For food or feed purposes, agriculture aims at the crop yield. For energy purposes, however, the total biomass yield can be applied rather than the crop yield. Therefore, this study considered the total biomass yield, which was calculated by dividing data on crop yields from the FAO (2007) by the HI. Table 1 shows the data on HI that were derived from agricultural studies (Goudriaan et al., 2001; Akhtar, 2004).

Biomass for energy can be divided into three categories: (i) trees; (ii) bio-energy crops; and (iii) food crops that can be applied for either food or energy. The study considered these three categories of crops and made assessments for fifteen plant species from the three categories mentioned above: poplar (tree), miscanthus (bio-energy crop), and for cassava, coconut, cotton, groundnuts, maize, palm oil, potato, wheat, rapeseed, sugar beet, sugar cane, sunflower, and soybean (food crops).

2.3. Energy from biomass

The basis for energy from biomass is the universal photosynthesis process that stores solar energy in chemical bonds.