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Where to produce rapeseed biodiesel and why? Mapping European rapeseed energy efficiency

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Rapeseed is widely used to produce biodiesel, especially in Europe. In several studies, it has been shown that there is a good potential for growing this crop across the continent. However there is still little awareness that the energy efficiency of biofuel production from rapeseed is very low. Energy efficiency can be expressed in terms of Energy Return for Energy Invested (EROEI). We mapped EROEI values for all EU countries plus Switzerland based on expected yields derived from rapeseed suitability maps. We find that EU countries produce rapeseed biofuel with EROEI values of 2.2 and lower. We suggest that plans for biofuel cropping have to be supplemented by maps of EROEI. It is not only relevant to show where rapeseed can be grown, but we should also look at where its use for bioenergy can be efficient. In the area theoretically suitable for growing rainfed rapeseed (excluding unsuitable areas and water), 37.6% of the area can produce rape methyl ester (RME) biofuel only with an energy loss. We conclude that the energy efficiency of rapeseed biodiesel is low and spatially heterogeneous, and unless there are major technological improvements in the production process, replacing fossil fuels by biofuels from rapeseed is hardly a feasible option.

1. Introduction

Energy is the driving force for economic development [1]. So far, fossil fuels (e.g. petroleum, coal etc.) are the main source of energy. Most of the advances in livelihoods and life quality that we enjoy today can be traced back to the abundant and cheap supply of fossil fuels that humanity has been enjoying over the past century. However, the present continuous reliance on fossil fuels becomes risky for several reasons. First and foremost, this resource is non-renewable and, currently its consumption is by far faster than its rate of formation, and even discovery. As reserves shrink, extracting fossil fuels becomes more difficult and expensive, and eventually will be cost inefficient. There are also environmental and human costs involved in extraction and production of fossil fuels. Besides, fossil fuel consumption produces greenhouse gases (GHG), which have been clearly shown to be a major driver of climate change globally [2,3]. According to some estimates, 80% of the remaining fossil fuel should stay in the ground if we are to avoid extreme consequences of climate change [4]. Moreover, much of the remaining fossil fuels are contained in and have to be imported from politically unstable countries, making supply unreliable [5]. These problems draw our attention to the search for alternative energy sources [6], out of which biofuel energy looks like a promising one. Compared to fossil fuels, alternative energy sources in general and biofuels in particular bear much promise in terms of lower environmental impacts, improved energy security and less socio-economic externalities [7–14].

Biofuels are derived from plants, and can be used directly for heat, electricity production or converted to liquid fuel [15]. This latter use makes them especially attractive as a substitute for energy in transportation, which currently predominantly relies on liquid fossil fuels. Currently biomass fuels are the only alternative to liquid fossil fuels [18,19], and, they can be used in unmodified conventional diesel-engines as in the case of Fischer–Tropsch (FT) biodiesel [20]. Worldwide corn, wheat, barley, sugarcane, rapeseed, oil palm, soybean, sugar beet, potato, sunflower [15–17], etc. are used for biofuel production. The European Union was the world

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leader in biodiesel and third in biofuel production in 2005 [7]. Out of the total of 10.2 billion liters of biodiesel produced worldwide in 2007, 60% was produced in the EU, where rapeseed is the major oil crop [7,16,25] accounting for more than half of the production [26]. In 2008, 79% of all biodiesel feedstock crops in Europe was rapeseed [16] and it was cultivated in most European countries [27,28].

The increasing demand for energy in general and the growing role of biofuels in meeting this demand makes it especially important to understand all the implications and consequences of biofuel production [24]. A major controversy is that biofuel production relies on the same crops that can be used for food production [7,21]. For example, biodiesel is mainly produced from vegetable oils such as rapeseed oil, sunflower seed oil, soybean oil, all of which can be also used in the food chain [12,21]. Growing demand for biofuels may increase food prices and has direct impact on land use and biodiversity [6,11,13,14,22–24]. Another major concern is the overall efficiency of biofuel production [29]. Agricultural systems vary in energy inputs and outputs. Different agro-ecological areas have different agronomic practices [10,30] and are influenced by different biophysical factors [31]. This in turn influences the efficiency of biomass production. Obviously, studying the energy efficiency of a biofuel production system under different agro-ecological and agricultural practices plays a vital role in selecting and optimizing the technology in each type of environment and understanding the overall viability of the biofuel future.

Production of energy from bio-resources is a function of land, labor, water, raw materials, etc. [35], which adds a strong spatial component to the process. Production has to occur on vast areas of land in various agro-ecological conditions [39]. There were previous attempts to present the spatial variability of rapeseed production in Europe [40]. Land suitability and potential yield of rapeseed was mapped on a 1 km grid base across Europe. In our study we expand these results by studying the efficiency of biofuel production and accounting for the energy input and output factors.

A widely used efficiency indicator of the energy production process is the energy return on energy investment (EROEI), which is calculated from the following equation [33–37]:

$$\mathrm{EROEI} = E_{\mathrm{out}}/E_{\mathrm{in}},$$

where E_{out} is the amount of energy produced, and E_{in} – the amount of energy used in production. Clearly, an EROEI value of close to one or less makes production thermodynamically meaningless as much or even more energy is needed for energy production than what is produced [38]. According to some estimates, a minimum EROEI of 3 should be achieved to make sure that the energy production is economically, environmentally and socially acceptable [34]. This is to compensate for numerous externalities involved in the process (land and water quality degradation, pollution, etc.), which are hard to express in energy values and fully account for in the EROEI calculations. There have been previously some concerns raised about the overall energy efficiency of biofuel production. For example, energy efficiency for corn ethanol for the entire US on county level (for yield) and state level (for fertilizers and irrigation) showed EROEI values ranging spatially from 0.87 to 1.27 [29]. In this paper we produce a spatial analysis of rapeseed energy production efficiency for Europe and show where it makes most sense to produce biodiesel from rapeseed and where it should be discouraged.

We largely base our results on a previous study of rapeseed EROEI [30]. In that study a computational input/output model was developed to determine energy production efficiency of the rapeseed biofuel production process comparing different farming systems. Interviews with Dutch farmers, conducted during that study also indicated that farmers do not care much for which purposes the crop is used. They will sell to a buyer from the food industry as well as to an energy producer or to any other buyer as long as they receive a good price for the product. The energy efficiency in the crop production stage is, therefore, not really much different for the various uses of the rapeseed oil. Therefore we assume that all areas are evaluated for their potential in producing rapeseed biofuel and to make clear where in Europe this may be energetically beneficial and where not.

Extending previous research on spatial variability of rapeseed production in Europe [40], we map the EROEI of this process to find that using this crop for bioenergy purposes also raises some concerns in terms of efficiency. We focus on biofuel production from winter rapeseed, which is the most abundant crop type due to a higher achievable crop yield compared to summer rapeseed. It is also more popular because having a crop with a high level of ground coverage on the land during winter reduces soil erosion and is considered more ecologically friendly [41].

2. Materials and methods

Mapping EROEI was carried out for the twenty-seven current member countries of the European Union and Switzerland. The approach was to combine a Life Cycle Inventory (LCI) based EROEI model and yield maps (derived from a suitability map) with long-term yield assessment. The underlying assumption is that the yield of rapeseed very much determines the energy production efficiency and varies with different agro-ecological conditions for the same production inputs. For our analysis, we use three major sources of information.

The Global Agro-Ecological Zones (GAEZ) project, a collaborative effort between the Food and Agricultural Organization of the United Nations (FAO) and the International Institute for Applied System Analysis (IIASA), has produced suitability maps for rain-fed oil crops for the whole of Europe. The GAEZ suitability map defines the percentage of the maximum attainable yield that can be expected for a given location based on the agro-ecological and climatic conditions there [40]. We combined the GAEZ suitability map with a computational input/output model that was based on Life Cycle Inventory and farmer interviews conducted in Poland and the Netherlands [30]. A previous paper by Firrisa et al. [30] describes in detail all inputs, outputs, assumptions and conversion factors used in this analysis. An important input parameter in the calculation model is the yield. By interpreting the suitability classes in terms of expected yields and linking them to the computational model described in Ref. [30] here we have produced energy efficiency maps for Europe. Next, we used FAO data on rapeseed production for the last 50 years [42] to validate and compare the results that came from the suitability analysis, and to refine the energy estimates based on country-specific conditions. We then used the map of rapeseed production in the Netherlands obtained from the Dutch Ministry of Agriculture [43] to zoom into country-specific conditions in the Netherlands.

The Global Agro-Ecological Zones (GAEZ) model utilized a land resources inventory to assess feasible agricultural land use options and to quantify expected yield resulting from cropping activities. The approach took into account specific agro-ecological contexts for well-specified management conditions and levels of inputs. The characterization of land resources included components of climate, soils and landform, which are basic for the supply of water, energy, nutrients and physical support to plants. The GAEZ suitability maps are based on a half-degree latitude/longitude world climate data set, 5-min soils data derived from the digital version of the FAO Soil Map of the World, the 30 arc-seconds Global Land Cover Characteristics Database, and a 30 arc-seconds digital elevation data set [44]. The resulting suitability map has eight suitability classes and a ninth class "water".