Chapter 2.2.2

Water Use for Biofuels in Europe

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1. INTRODUCTION

By providing tax credits and tax exemptions and by introducing minimum blending requirements for biofuels, the United States and the European Union embarked on promoting the use of biofuels (ethanol and biodiesel) in the early 2000s.[1] Many other countries, including Canada and India, followed. The United States and the European Union implemented their biofuel policies with the objective of reducing greenhouse gas emissions and dependence on imported oil in the transport sector; promoting the security of energy supply by increasing domestically produced energy; promoting technological development and innovation; and providing opportunities for employment and regional development in rural and isolated areas.

The European Union is an important producer and consumer of biofuels in the world market. Fig. 1 presents the production of ethanol (the solid line) and biodiesel (the dashed line) in the EU-28 in the period 2002−2013. While the production of both biofuels was increasing up until 2010, biodiesel production has been significantly higher for two main reasons: biodiesel targets were higher compared to the ethanol targets and the consumption of diesel (with which biodiesel is blended) has historically dominated gasoline consumption. Germany, France, and the Netherlands are the leading biodiesel producers (European Biodiesel Board, 2015).

Although a debate on the effects of biofuels on food commodity prices has been going on for a few years, a debate on water use for production of biofuels appears far less intensive. This is striking as biofuel production and water use are intimately connected through agricultural crops that serve as feedstock for first-generation biofuels (ie, biofuel produced from crops that are also used for food production).

More generally, agriculture is the major source of nitrogen pollution of European water bodies, including lakes, rivers, groundwater, and the European seas (European Environment Agency, 2015). More intensive agricultural crop production in the European Union because of higher food commodity prices (caused in part by biofuel policies) and limited land expansion potential aggravates this pollution even more. The agricultural sector also accounts for a large proportion of water use across Europe, particularly in southern

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[1] Biofuels were produced also before 2000, but at a much smaller scale.

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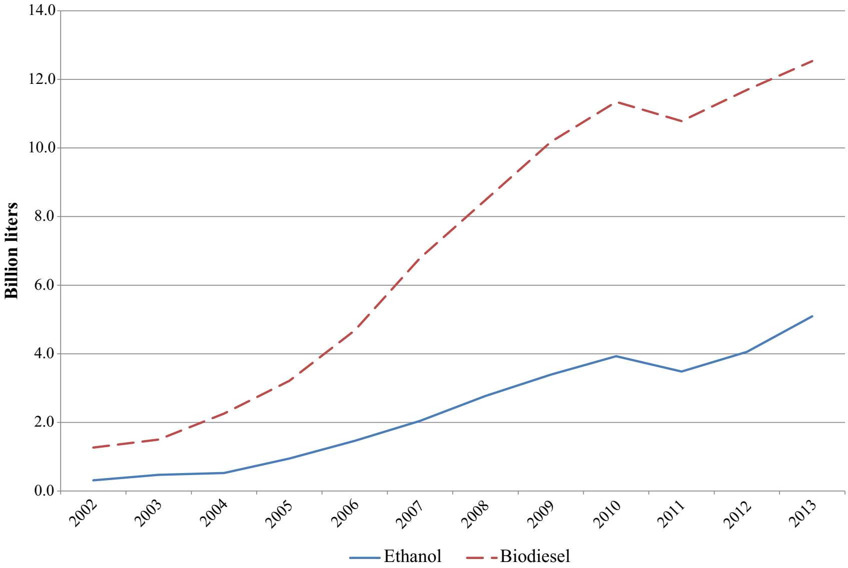

FIGURE 1 Production of biofuels in the EU-28. Note: Eurostat data in 1000 tonnes of oil equivalent (toe). 1 toe = 39,683,207.2 British thermal units (BTUs), 1 L of ethanol = 20,103.503 BTUs, and 1 L of biodiesel = 31,251.569 BTUs. *Eurostat, 2015b. Primary Production of Renewable Energy by Type. Reproduced from http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00081&language=en.*

countries where the importance of irrigation means that agriculture can account for as much as 80% of total water use in some regions (European Environment Agency, 2009).

Therefore the objective of this chapter is to provide a closer look at the nexus of biofuels and water use in the European Union, especially from an economic point of view. We focus on first-generation biofuels, as these are currently predominantly produced. Since water use to process feedstock into biofuel is comparatively smaller than the amount of water used during the cultivation of biofuel feedstocks, we focus on the latter.

We argue that technical indicators of water efficiency in biofuel production that ignore market-mediated effects (through prices) of biofuel policies can lead to misleading estimates of water consumption for biofuel production. To solve this issue, one needs to calculate not only how much water corresponds to a unit of energy delivered to the market, but also by how much demand for agricultural crops will decline in response to higher food commodity prices.

We find that by determining the dominant biofuel type (biodiesel), EU energy policies essentially determine the domestic water use in biofuel production and also affect water use in the main biofuels (feedstock) import markets. From an economic point of view, water is one of many inputs used to produce biofuel feedstocks and biofuels. Therefore if properly priced, water codetermines the efficiency of biofuel production; that is, if externalities of water use are properly internalized into the price of water, they will also be taken into account as a weight on the water input to influence the cost of biofuel production.

To better understand the driving forces of EU biofuel production, in the next chapter we discuss the main EU biofuel policies.

2. EU BIOFUEL POLICIES

The policies governing the production and consumption of biofuels in the European Union are complex. The complexity has three main dimensions. First, biofuel production and consumption are regulated by the Renewable Energy Directive (RED) (Directive 2009/28/EC) and the Fuel Quality Directive (FQD) (Directive 2009/30/EC). Second, EU biofuel policies are shaped by three EU institutions: the Commission, the Parliament, and the Council. In addition, a number of pro- and antibiofuel lobby groups are active in (re) designing biofuel policies. For example, many EU biodiesel producers are associated in the European Biodiesel Board; ePURE represents the European renewable ethanol industry; and Copa-Cogeca, representing European farmers and their cooperatives, supports the production of first-generation biofuels. On the other hand, nongovernmental organizations such as Transport and Environment or Greenpeace are against land-based (ie, first-generation) biofuels. Third, although the EU directives state general objectives to be achieved and principles to be followed at the EU level, the actual implementation of the biofuel legislation differs across the 28 EU Member States (Table 1).

Large-scale biofuel production in the European Union started only after May 2013, when the EU Parliament and the Council passed Directive 2003/30 on the promotion of the use of biofuels for transport. The objectives of this Directive were to replace diesel and gasoline in the transportation sector to contribute to (1) meeting the EU climate change commitments, (2) achieving environmentally friendly security of energy supply, and (3) promoting renewable energy sources. Directive 2003/30 set an indicative target of 2% by 2005 for each Member State for the share of energy coming from biofuels and other renewable fuels in the total energy of fuels used in the transportation sector; the Directive also stipulated a target of 5.75% by 2010.

It is important to notice that the targets in Directive 2003/30 were (and to this date are) expressed as energy shares, as opposed to volumetric shares used in other countries (eg, the United States or Brazil). Most importantly, however, the targets were not binding, which is indicated by Article 4 of the Directive: "Where appropriate, Member States shall report on any exceptional conditions in the supply of crude oil or oil products that have affected the marketing of biofuels and other renewable fuels." This article implies that as long as a Member State was able to explain why a lower energy share of biofuels had been achieved, no consequences followed. Illustrating the nonbinding character of the target, the share of biofuels in total transportation fuels in the European Union reached 1.65% in 2006 and 4.05% in 2010 (USDA, 2010). Furthermore, 22 out of 27 EU Member States failed to achieve their target for 2010 (European Commission, 2013).

Another big milestone in the development of EU biofuel policies was the year 2009 when the RED and the FQD became EU laws. The RED requires (among other things) that by 2020 at least 10% of the total energy consumed in the EU transportation sector comes from renewable sources. Although it is expected that the lion's share of the target will be met by biofuels, other renewable sources of energy (such as renewable electricity) can also be counted. Unlike Directive 2003/30, the RED explicitly uses the term "mandatory target," although it does not specify any enforcement mechanisms.

Although the RED stipulates an overall blend target (ie, ethanol and biodiesel combined, bar the tiny share of other renewable energy sources), each Member State specifies its own trajectory to achieve the overall 10% goal by 2020 and can set ethanol- and biodiesel-specific submandates.

Another important piece of legislation affecting the production and consumption of biofuels in the European Union is the FQD of 2009. The FQD addresses the reduction in

TABLE 1 **Minimum Biofuel Consumption Target in Energy Content for 2014**

	Overall Target (%)[a]	Ethanol Target (%)[a]	Biodiesel Target (%)[a]	Gasoline Consumption (million liters)[b]	Diesel Consumption (million liters)[b]
France	7.57	7.00	7.70	619.7	2589.4
Poland	7.10			336.5	722.9
Slovenia	7.00			44.6	102.5
Sweden	6.41	3.20	8.78	244.8	303.3
Germany	6.25	2.80	4.40	1617.6	2524.3
Finland	6.00			128.8	196.0
Lithuania	5.80	3.34	6.45	19.3	85.2
Austria	5.75	3.40	6.30	143.5	451.7
Denmark	5.75			122.8	185.4
Portugal	5.50			105.5	303.6
Netherlands	5.50	3.50	3.50	363.8	510.3
Belgium	5.09	2.66	5.53	109.7	544.5
Ireland	4.94			109.1	184.7
Bulgaria	4.94	3.34	5.53	40.7	112.3
Hungary	4.90	4.90	4.90	109.7	164.0
Romania	4.79	3.00	5.53	116.6	280.8
Luxembourg	4.75			30.1	143.4
Czech Republic	4.57	2.73	5.53	144.7	290.2
Slovakia	4.50	2.73	6.27	51.7	109.5
Italy	4.50			772.4	1735.2
Malta	4.50			6.8	7.9
Spain	4.10	3.90	4.10	429.1	1669.1
United Kingdom	3.90			1236.8	1924.4
Greece	2.64			260.6	165.4
Croatia	2.06			55.3	96.1

[a] *Biofuels barometer (2014).*
[b] *Eurostat (2015a), consumption data for 2013.*

life cycle greenhouse gas emissions of transportation fuels by 6% by the year 2020 as compared to 2010. With respect to biofuels, it specifies criteria that need to be met for biofuels to count toward the mandatory consumption targets.

Perhaps the most important of these criteria is a requirement that biofuels should save at least 35% of greenhouse gas emissions compared to fossil fuels they are to replace. This threshold increases to 50% on January 1, 2017. Moreover, from January 1, 2018 the saving shall be at least 60% for biofuels produced in plants that started production on or after January 1, 2017. It is important to note, however, that these specified greenhouse gas emissions savings do not take into account carbon emissions from land use change, a topic that gave rise to a heated debate on biofuels in the European Union after 2012.

Moreover, the FQD allows imports of biofuels or biofuel feedstocks only from countries that have ratified important international conventions such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora, the Cartagena Protocol on Biodiversity, or conventions of the International Labor Organization.

The food commodity price booms of 2008 and 2011 and the intensifying “food versus fuel debate” have been an impetus for the reform of the EU biofuel policy. In October 2012, the European Commission proposed to reform the EU biofuel policy (represented by the RED and FQD directives).[2] The Commission has assigned indirect land use change (ILUC) factors to different biofuels but failed to account them for the climate performance of biofuels. Thus the ILUC factors are used only for reporting purposes. In recognition of adverse inflationary effects of first-generation biofuels on food commodity prices, the Commission proposed to cap the use of these biofuels to 5% of energy. Environmentalists, such as Transport and Environment—a Brussels-based environmental organization—opposed this proposal as it did not mean complete abolition of biofuels produced from food crops.

The reshaping of the EU biofuel policy continued in July 2013 when the European Parliament’s Environmental Committee voted for the inclusion of the ILUC factors into the RED and for capping all first-generation biofuels at 5.5% of energy. Later in September 2013 the European Parliament voted to cap the first-generation biofuels at 6% and placed a 2.5% minimum requirement to be achieved by 2020 for advanced (third-generation) biofuels from, for example, seaweed or certain types of waste (European Parliament, 2013). In June 2014 the Council of energy ministers decided to cap the use of land-based biofuels to 7% and to put a 0.5% floor on advanced biofuels.[3] After long discussions, the EU Parliament finally approved the Council’s proposal on April 14, 2015. These policy developments will have long-term implications for water use in biofuel production in the European Union as they cap the use of land-based biofuels, the production of which requires significant quantities of water.

Besides biofuel policies, water protection regulations also affect the biofuels−water nexus in the European Union. This we discuss next.

3. WATER PROTECTION REGULATIONS IN THE EUROPEAN UNION

The Water Framework Directive (WFD) (Directive 2000/60/EC) is the key regulation that protects water resources in the European Union. It is the first directive to consider not only

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[2] http://ec.europa.eu/clima/policies/transport/fuel/docs/com_2012_595_en.pdf.

[3] http://gr2014.eu/sites/default/files/indirect%20land-use%20change_1.pdf.

water quality, but also quantity (Chave, 2001). This is important because biofuel production imposes significant changes in the amount of water used. To improve the quality of natural waters in individual EU Member States, the main objectives of the WFD are to (1) prevent any further deterioration of water bodies, (2) protect and enhance the status of aquatic ecosystems and associated wetlands, (3) promote sustainable water consumption, and (4) contribute to the mitigating effects of floods and droughts. One of the priority issues of the WFD is the adoption of industry-specific measures since in many cases water pollution was caused by specific types of industry that were much more significant in the context of their impact on water quality than others.

The RED, which stipulates mandatory consumption targets for biofuels, also specifies biofuel sustainability criteria that include water use. For example, biofuels are only counted toward the consumption target if they were not made from raw material obtained from wetlands, namely, land that is covered with or saturated by water permanently or for a significant part of the year. In addition, the RED requires each Member State to estimate the biofuel production impact on water resources and water quality (among other indicators) within its territory.

The economic implication of these two directives is that they partially internalize negative externalities related to water use in biofuel production, thus bringing the water price closer to water's social marginal costs. The negative externalities related to water use for biofuels include, for example, over use of water in some areas because of irrigation or pollution of groundwaters with fertilizers because of intensive production of biofuel crops.

Since most water in biofuel production is used during the cultivation of biofuel feedstock, and because a type of feedstock is determined by the type of biofuel, we now look into the main biofuel crops produced in the European Union.

4. BIOFUEL TARGETS AND FEEDSTOCK USE IN THE EUROPEAN UNION

Table 1 summarizes the minimum biofuel consumption targets (in energy terms) of selected EU Member States for the year 2014 as reported by the Biofuels barometer. France has the highest target of 7.57 energy percent, while Croatia is at the bottom of the list with 2.06%. Observe that most Member States also specify minimum ethanol and biodiesel submandates. For example, Germany requires that ethanol constitutes at least 2.8% of energy of motor gasoline fuel (ie, gasoline blended with ethanol), and the requirement for biodiesel is 4.4%. Notice, however, that these are minimum requirements since the overall target for Germany is 6.25 energy percent.

Comparing the mandates in the second and third columns of Table 1, we see that of the Member States that have biofuel-specific mandates, a majority (save for the Netherlands and Hungary) favor biodiesel. Because percentages can be misleading if the corresponding bases to which they relate differ, we present the 2013 quantities of gasoline and diesel consumed in the last two columns. (The 2014 Eurostat data were not available at the time of writing.) A higher relative consumption of diesel to gasoline in all EU Member States (except for Greece) puts even more weight on the higher percentage biodiesel submandates. This has an additional effect on the quantity of biodiesel in that it is higher than ethanol. The specification of submandates has important implications for water use as biodiesel feedstocks have different water balances compared to ethanol crops.

Most biofuels currently used in the European Union are derived from crops that can also be used for food production. The main crops processed into first-generation ethanol are wheat, corn, barley, and sugar beet. Wheat is mainly used for ethanol in northwestern Europe, including the United Kingdom. Corn is mainly used in Central Europe and Spain, whereas barley and rye are processed in Germany, Sweden, Poland, and the Baltics. Germany, France, and the Czech Republic derive ethanol also from sugar beet. Wine and wine by-products are important in regions of Italy (USDA, 2014).

Rapeseed oil has been the dominant biodiesel feedstock in the European Union; in 2013 it accounted for 58% of total biodiesel production (USDA, 2014). Palm oil is the second most important biodiesel feedstock used in the Benelux, Spain, Germany, Italy, and Finland. It has gained popularity because of its lower price compared to other feedstocks. However, the use of palm (and soybean) oil in conventional biodiesel is limited because of technical issues related to the iodine value of the fuel.[4] Soybean oil has primarily been used in Spain, France, Italy, and Portugal. After Austria, Denmark, Finland, France, Germany, Ireland, the Netherlands, and the United Kingdom introduced double-counting of biodiesel produced from used cooking oil, the use of this (recycled) feedstock has increased. Because the demand for biodiesel feedstock in the European Union exceeds the supply, the feedstock is imported either in its unprocessed form (soybeans and rapeseed) and is crushed domestically, or it is imported directly as vegetable oil (approximately 1.5 million metric tons) (USDA, 2014).

Fig. 2 depicts the area under the main crops used for biofuel production in the EU-28. Wheat leads the list with almost double the area of barley and triple that of corn. The area under rapeseed cultivation is comparatively smaller and soybean area is close to zero. The relatively small areas of oilseeds compared to ethanol crops explain the excess demand for biodiesel feedstock that needs to be imported. The figure also shows long-term stability of areas under individual crops, which indicates that the growth in food crop commodity prices in 2008 and 2011 did not affect the relative prices among commodities (de Gorter et al., 2015).

The revision of the EU RED has seen a cap on the use of the first-generation biofuels, thus encouraging the introduction of second-generation biofuels. A 2012 proposal of the EU Parliament and the Council[5] suggested that biofuel produced from the following feedstocks be considered at twice their energy content: used cooking oil, animal fats, nonfood cellulosic material, lignocellulosic material except saw logs and veneer logs. In addition, the proposal also lists a set of biofuel feedstocks that are to be counted four times their energy content toward the mandate: algae, biomass fraction of mixed municipal and industrial waste, straw, animal manure and sewage sludge, palm oil mill effluent and empty palm fruit bunches, tall oil pitch, crude glycerin, bagasse, grape marcs and wine lees, nut shells, husks, cobs, bark, branches, leaves, saw dust, and cutter shavings.

In the next section, we investigate how feedstocks for first-generation biofuels perform in terms of water use.

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[4] Iodine value is an important parameter describing oil, fat, as well as biodiesel characteristics. Heated fuels with a high iodine value tend to polymerize and form deposits on engine nozzles, piston rings and piston ring grooves.

[5] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012PC0595&from=EN.

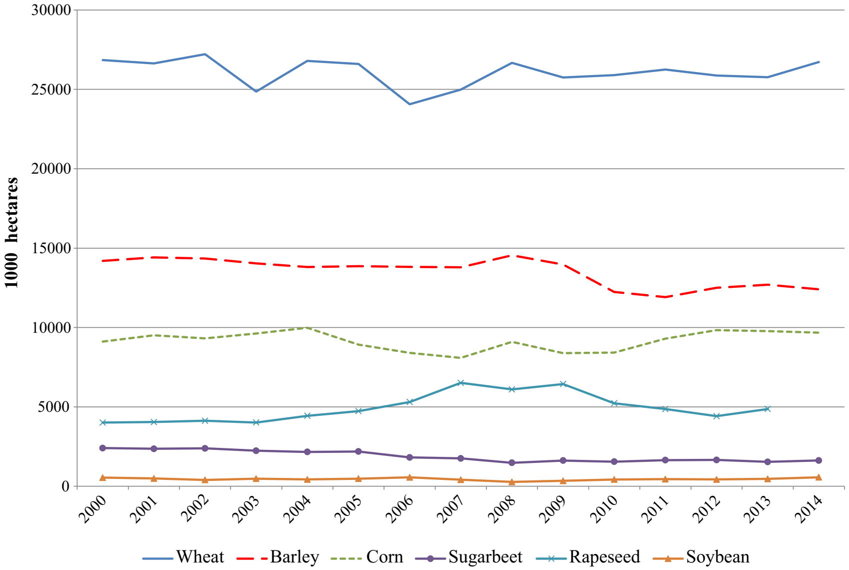

FIGURE 2 Area under the main biofuel feedstocks in the EU-28. *Eurostat, 2015c. Crops Products – Annual Data. Reproduced from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apro_cpp_crop&lang=en.*

5. TECHNICAL INDICATORS OF WATER EFFICIENCY IN BIOFUEL PRODUCTION

Most water use related to biofuel production occurs during the cultivation of biofuel feedstock (de Vries et al., 2010). We therefore focus on this stage. We look at two possible criteria that measure water intensity of biofuels and their feedstocks: the virtual water content (VWC) and the water productivity of biofuels (WPB). It should be noted that these technical criteria often used in scientific literature do not take into account commodity market prices and are only partial indicators of water use efficiency as they are unable to reflect other market effects (eg, competition for land). We will discuss an economic evaluation of efficiency of biofuel production in Section 6.

The VWC of a product is defined as the volume of water used to produce the product (eg, a crop), measured at the place where it was actually produced (Chapagain and Hoekstra, 2004, 2007). With respect to biofuels it means the total quantity of water needed to produce a metric ton of a biofuel feedstock (eg, corn or rapeseed). The upper part of Table 2 presents estimates of virtual water contents for the main biofuel feedstocks in selected EU Member States.[6] The VWC varies significantly both across feedstocks and among Member States, reflecting different technological and climatic conditions in cultivation. For feedstocks, sugar beet exhibits the lowest, while rapeseed tends to have the

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[6] We do not present values for soybeans as their production in the European Union is very low, and more so in individual Member States.

TABLE 2 Virtual Water Content and Energy From Select Biofuel Feedstocks

	Wheat	Corn	Barley	Sugar Beet	Rapeseed
VWC in m^3/ton[a]					
Austria	981	357	967	60	1341
Belgium–Luxembourg	1168	597	1237	108	1841
Czech Republic	1180	564	1248	93	1395
France	895	482	886	63	1390
Germany	757	442	826	77	1128
Greece	1213	706	1112	121	NA
Hungary	556	666	637	94	539
Italy	2421	530	1822	117	5095
Netherlands	619	408	718	65	1182
Romania	759	1271	758	190	718
Slovakia	465	646	584	88	382
Spain	1227	646	1070	113	3284
Ukraine	720	1362	894	218	664
United Kingdom	501	NA	650	56	876
Energy of biofuel/ton of feedstock[b] (GJ/ton)	10.17	10	10.2	2.61	11.7

VWC, virtual water content; *NA*, not available.
[a] *Chapagain and Hoekstra (2004).*
[b] *Mekonnen and Hoekstra (2010).*

highest VWC. The pattern is more blurred across Member States, with the VWC in some Member States being a multiple of others (eg, compare wheat in Italy and Slovakia).

The last row of Table 2 presents the gross energy content (ie, unadjusted for the energy input) of biofuels derived from a metric ton of feedstocks. The gross energy content is independent of where the feedstock is produced. Interestingly, the variation in the gross energy content per ton of biofuel feedstocks is much lower than for the VWC. The only exception is sugar beet that yields only 2.61 GJ of ethanol per metric ton. However, this energy "disadvantage" is accompanied by a significantly lower VWC of the crop. To see how much water is needed to produce one GJ of biofuels, one needs to divide the VWC of a crop by the corresponding energy content reported in the last row of Table 2. Then, for example, for corn and sugar beet in Germany we obtain 44.2 m^3/GJ (=442/10) and 29.5 m^3/GJ (=77/2.61), respectively. Thus, considering only the gross energy yield of a feedstock, the VWC to produce 1 GJ is lower for sugar beet than for corn in Germany.

Although informative, the two measures presented in Table 2 provide little guidance as to what biofuel feedstock could be appropriate (ignoring market prices) if a country has limited availability of water resources to use in biofuel production. It is because the amount of energy used to produce the feedstock is omitted. A more suitable measure is the water productivity of biofuels (WPB). deVries et al. (2010) define this productivity measure as the amount of *net* biofuel energy (ie, deducting the energy needed to produce a biofuel) that is produced using 1 m^3 of water lost through evapotranspiration.

de Vries et al. (2010) examine a number of studies to estimate the mean value of the WPB. Their results are summarized in Fig. 3. Biofuel production from oil palm, sweet sorghum, and sugarcane appear relatively water efficient given how much net energy of biofuels is associated with 1 m^3 of water used. Intriguingly, sugar beet and rapeseed also perform relatively well. Sugar beet is characterized by a high (fresh) biomass production per volume of water consumed (about double that of sugarcane). However, net energy production of sugar beet ethanol is relatively low because of consumption of large quantities of fossil fuels during processing, while energy required for sugarcane processing is mostly supplied by crop residues (bagasse). Although a metric ton of rapeseed requires significant quantities of water (Table 2), it does at the same time exhibit a favorable net energy yield of 9.1 GJ per ton of processed rapeseed, resulting in a relatively high WPB.

Now we are in a position to evaluate the effects of increased EU biofuel consumption on total water use in EU agriculture. The values in Table 1 suggest that the consumption of biodiesel in the European Union is higher relative to ethanol for two reasons. First, EU Member States mandate higher shares of biodiesel than ethanol, and second, the consumption of diesel in the European Union has historically been greater than the

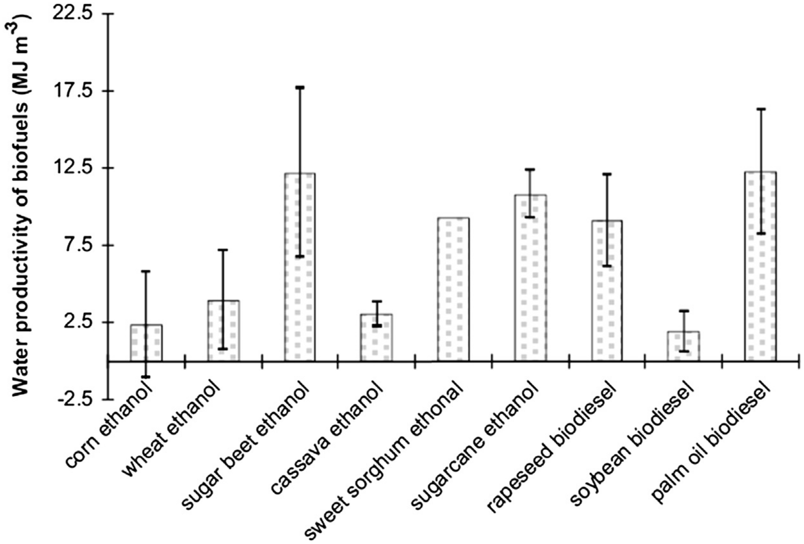

FIGURE 3 Water productivity of biofuels by feedstock. *Modified after de Vries, S.C., van de Ven, G.W.J., van Ittersum, M.K., Giller, K.E., 2010. Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques. Biomass and Bioenergy 34, 588–601.*

consumption of gasoline. Combining the observed feedstock use pattern of ethanol (wheat, corn, and sugar beet) and biodiesel (rapeseed and palm oil) with the water productivity of individual feedstocks in Fig. 3, we come to a conclusion that for a given overall biofuel mandate, water use for biofuels decreases with a higher share of biodiesel. The implication of this finding is that if the European Union wants to achieve a 10% share of renewable energy in total transportation energy consumption, and at the same time minimize biofuels-related water use, the blending submandates for biodiesel should increase faster relative to the ethanol submandates.

The earlier conclusion is based on the comparison of the observed biofuel consumption pattern with a counterfactual where ethanol exhibits a higher share. No attention was paid, however, to where the feedstock for the increased biofuel consumption comes from. Fig. 2 shows a stable area under the main biofuel crops in the European Union over time. The stable area of biofuel crops implies unchanged water use for biofuels produced from domestic EU feedstock. However, because of growing biofuel consumption and stable production of domestic feedstock, the difference has to be covered by imports of biofuels or feedstocks (to be processed in biofuels or human consumption). Therefore whether the growing EU biofuels consumption increased or decreased, overall water use depends on the change in the area of biofuels feedstock in the rest of the world.

The imported palm oil is the second most used biodiesel feedstock in the European Union. Because of the favorable water productivity of oil palm relative to other feedstocks (Fig. 3), the additional acreage of oil palm in other countries (mostly Indonesia and Malaysia) could have decreased water use, but only if the crops that otherwise would have been grown in those places were more water-intensive. The net effect is therefore ambiguous because of the EU biofuel policy-induced indirect land use changes (Zilberman et al., 2011; Khanna et al., 2012), and thus cannot be determined a priori without an empirical analysis.

Because these (partial) water efficiency measures do not take into account market prices of biofuels and of their inputs, in the following section we advance a way to incorporate these important market characteristics into the assessment of efficiency of biofuel production.

6. A COMPREHENSIVE WAY TO ASSESS THE EFFICIENCY OF BIOFUEL PRODUCTION

To illustrate how to include market effects of biofuel policies to avoid misleading estimates of water consumption for biofuel production, we focus on biodiesel produced from rapeseed oil. Unlike corn and wheat, which are directly processed into ethanol, rapeseed needs to be crushed first, yielding oil and meal. The oil is then processed into biodiesel. Because the two-stage biodiesel production process would complicate our graphical exposition, in the left panel of Fig. 4, we directly present supply of rapeseed oil, S_{RO}, that is linked to the underlying rapeseed supply curve. Depicted in the left-hand panel is also the demand for nonbiodiesel oil, D_{NBRO}, used, for instance, in human consumption.

If biodiesel were not produced, the intersection of the oil supply and demand curves would determine the oil price denoted by P_{NB}, with the subscript NB denoting nonbiodiesel. Suppose the oil price increases above P_{NB}, for example, because of biodiesel production. Then the quantity of oil supplied exceeds the quantity demanded for nonbiodiesel use and the excess supply of oil is diverted to biodiesel production. In Fig. 4 this

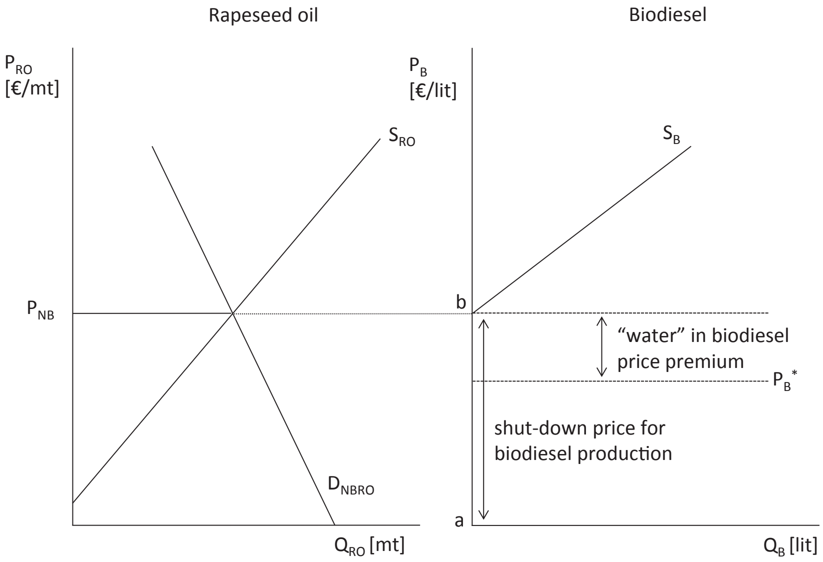

FIGURE 4 Economic efficiency of biofuel production.

is depicted in the right-hand side panel where the curve S_B is derived as a horizontal difference between the S_{RO} and D_{NBRO} curves in the left-hand panel. Point b on the biodiesel supply curve then corresponds to the price P_{NB} in the left-hand panel. Because the measurement units in both panels differ, the prices and quantities need to be properly converted. Specific equations linking the rapeseed and biodiesel market can be found in Drabik et al. (2014).

One implication of Fig. 4 is that the intercept of the biodiesel supply curve is never at zero, meaning that there is always a positive shutdown price for the industry. Another implication has to do with the relative magnitude of the shutdown price and the free market biodiesel price.

The free market biodiesel price is the price that biodiesel producers would receive if consumers were free to choose a fuel (ie, biodiesel or diesel in our case) based on the number of kilometers a vehicle could travel per unit of a respective fuel, and if no biofuel consumption subsidy (a tax credit or a tax exemption) were provided. Mathematically, this price can be written as (Drabik, 2011)

$$P_B^* = \gamma P_D - (1-\gamma)t, \tag{1}$$

where $\gamma = 0.91$ denotes kilometers traveled per liter of biodiesel relative to diesel;[7] P_D denotes the diesel market price, and t denotes the fuel tax. The biodiesel price that

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[7] Calculated as the ratio of the energy content of a liter of biodiesel (31251.6 BTUs, British thermal units) and a liter of diesel (34210.3 BTUs). The actual relative kilometers traveled per liter of both fuels might differ slightly from this ratio because there is not a one-to-one correspondence between energy of fuel and the distance it yields (consider, for example, different driving styles or varying weather conditions during a year).

consumers are willing to pay is lower than the price of diesel for two reasons. First, consumers are willing to pay only 91% of the price of diesel per liter of biodiesel because of fewer kilometers traveled per liter of biodiesel relative to diesel. Second, there is a penalty on blenders because of the volumetric fuel tax. Consumers are willing to pay a fuel tax only on biodiesel that is proportional to its kilometers per liter, γt, but blenders have to pay the full tax, t. Therefore the difference $(1-\gamma)t$ represents the penalty on biodiesel (reflected in lower biodiesel market prices) because of the volumetric fuel tax. The penalty increases in countries with high fuel taxes and hence makes the production of biodiesel less attractive.

The relative position of the biodiesel free market price and the intercept of the biodiesel supply curve is an empirical issue and depends on the prevailing diesel price and the fuel tax as well as on the relative position of the rapeseed oil supply and demand curves. As Fig. 4 shows, when the free market biodiesel price is below the intercept of the biodiesel supply curve, free market would not support biofuel production. Intuitively, the fossil fuel (diesel) is less expensive than the alternative product (biodiesel).

This has important welfare implications because if biodiesel production does occur because of biofuel policies (eg, the EU Member States' biodiesel targets), then part of the biofuel policy price premium (ie, the difference between the observed and free market biofuel prices) is not effective in increasing the biofuel production; it just fills up the gap between P_{NB} and P_{B}^{*}. Using the jargon of international economics, de Gorter and Just (2008) term this gap "water" in the biofuel price premium.[8] This means that within the range of "water," a biofuel policy has no effect on feedstock prices. Alternatively, "water" can be thought of as representing the waste of societal resources because diesel (fossil fuel) is less expensive and yet production of more costly biofuel is incentivized through biofuel policies.

Although the economic term "water" (as a measure of policy inefficiency) might be confusing in the discussion of liquid "real" water use for biofuel production, we show that it is useful in explaining why (liquid) water use should not be taken as the key indicator of efficiency of biofuel production.

Consider again the rapeseed oil supply in the left panel of Fig. 4. It is derived directly from the rapeseed supply curve that reflects the (private) marginal production costs associated with rapeseed production. In theory, the marginal cost curve encompasses the competition for land use among crops (eg, wheat or corn vs. rapeseed or soybean); the effects of biofuel policies; and, last but not least, the actual water use in rapeseed production. It is important, however, that water be priced properly so that its true cost is reflected in the social marginal cost of feedstock production. It then follows that water is but one of many components that determine the position of the intercept, and therefore also the level of "water" (ie, the economic term).

Therefore to determine which biofuel is more efficient to produce and from which feedstock, one needs to estimate the level of "water" for every biofuel−feedstock pair and then choose the one with the lowest "water" levels. This is an empirical question left for further research.

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[8] International economics literature uses the term "water" in an import tariff to represent the difference between bound (ie, the highest permitted) and applied (ie, actual) duties.

7. CONCLUSIONS

Water is a key input into production of agricultural crops that are later processed into biofuels. As global consumption of biofuels gradually increases and water becomes scarcer (and more so in different parts of the world), the nexus between biofuels and water becomes more important. In this chapter, we have looked at water use for biofuels in Europe. We have focused on the first-generation biofuels, as these are currently predominantly produced in the European Union, and particularly on the water used during the cultivation of biofuel feedstocks since the amount of water for processing feedstock into biofuel is comparatively smaller.

We find that most EU Member States mandate higher shares of biodiesel relative to ethanol, thus favoring the former. In addition, facing a lower fuel tax, diesel consumption in the European Union has historically been advantaged over gasoline. As a result, more diesel is being consumed in each EU Member State (except for Greece), thus reinforcing the need for biodiesel (as the percentage target applies to a larger base). This implies that by determining which biofuel will be dominant in the European Union, the EU energy policies essentially determine the domestic water use in biofuel production. We show that for a given overall biofuel mandate, water use for biofuels decreases with a higher share of biodiesel.

Because the EU demand for biodiesel is short of supply, many Member States import the biofuel feedstock or biodiesel directly from abroad. This means that EU energy policies also have repercussions for water use in other countries of the world, depending on where biofuels are imported from and the feedstock used. However, since the European Union as a whole is currently consuming only about a half of the 10% target for 2020, and because imports of biofuels (in various forms) play an important role in biofuel consumption, one can expect that EU biofuel consumption will exert even greater pressure on global water use.

Unlike previous scientific literature that determines the efficiency of biofuel production based on partial and mutually disconnected indicators that ignore commodity market prices and market interactions, we stress a holistic economic approach. From an economic point of view, water is one of many inputs used to produce a biofuel feedstock and later a biofuel. Therefore if properly priced (which is likely not the case now), water codetermines the efficiency of biofuel production, but there is no reason to assume that all factors should have the same weights (eg, as in de Vries et al., 2010); the importance of individual inputs is determined by (correct) market prices.

We stress that technical indicators of water efficiency in biofuel production that ignore market-mediated effects (through prices) of biofuel policies can lead to misleading estimates of how much more water is needed because of biofuel production. That is to say, one needs to mechanically calculate not only how much water corresponds to a unit of energy delivered to the market, but also by how much demand for agricultural crops will decline in response to higher food commodity prices.

Finally, dwindling resources of fossil fuels suggest that consumption of biofuels in the European Union will not vanish but is likely to increase over time. So what is the way forward with respect to water use in this scenario? The recent reform of the EU biofuel policies that capped the consumption of first-generation biofuels at 7% of energy is one avenue. Another is improvement of productivity and development of crops with a lower water use; this would improve the efficiency of biofuel production from a water-efficiency perspective. The development of plant cultivars, for example, through a more intensive exploitation of biotechnology, that would require less water, produce higher yields, or be drought resistant would improve the water efficiency of biofuel production as well (eg, Hochman et al., 2008).

REFERENCES

Biofuels Barometer, 2014. A Study Carried Out by EurObserv'E. http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro222_en.pdf.

Chapagain, A.K., Hoekstra, A.Y., 2004. Water footprints of nations. In: Volume 1: Main Report. Value of Water Research Report Series. UNESCO-IHE Institute for Water Education, Delft.

Chapagain, A.K., Hoekstra, A.Y., 2007. Water footprints of nations: water use by people as a function of their consumption pattern. Water Resources Management 21, 35–48.

Chave, P., 2001. The EU Water Framework Directive: An Introduction. IWA Publishing, London, UK, 208 pp.

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. http://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF.

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN.

Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 Amending Directive 98/70/EC as Regards the Specification of Petrol, Diesel and Gas-Oil and Introducing a Mechanism to Monitor and Reduce Greenhouse Gas Emissions. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0030&from=EN.

Drabik, D., December 2011. The Theory of Biofuel Policy and Food Grain Prices. Working Paper 2011–20. Charles H. Dyson School of Applied Economics and Management, Cornell University.

Drabik, D., de Gorter, H., Timilsina, G.R., 2014. The effect of biodiesel policies on world biodiesel and oilseed prices. Energy Economics 44, 80–88.

European Biodiesel Board, 2015. The EU Biodiesel Industry: 2013 Production by Country. http://www.ebb-eu.org/stats.php.

European Environment Agency, 2009. Water Resources Across Europe—Confronting Water Scarcity and Drought. EEA Report No 2/2009.

European Environment Agency, 2015. SOER 2015—The European Environment—State and Outlook 2015. http://www.eea.europa.eu/soer.

European Commission, March 2013. Renewable Energy Progress Report. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0175:FIN:EN:PDF.

European Parliament, 2013. European Parliament Backs Switchover to Advanced Biofuels. http://www.europarl.europa.eu/news/en/news-room/content/20130906IPR18831/html/European-Parliament-backs-switchover-to-advanced-biofuels.

Eurostat, 2015a. Supply, Transformation and Consumption of Oil – Annual Data. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_102a&lang=en.

Eurostat, 2015b. Primary Production of Renewable Energy by Type. http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00081&language=en.

Eurostat, 2015c. Crops Products – Annual Data. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apro_cpp_crop&lang=en.

de Gorter, H., Just, D.R., 2008. 'Water' in the U.S. ethanol tax credit and mandate: implications for rectangular deadweight costs and the corn-oil price relationship. Applied Economic Perspectives and Policy 30 (3), 397–410.

de Gorter, H., Drabik, D., Just, D.R., 2015. The Economics of Biofuel Policies: Impacts on Price Volatility in Grain and Oilseed Markets. Palgrave Studies in Agricultural Economics and Food Policy. Palgrave Macmillan, New York, 316 pp.

Hochman, G., Sexton, S.E., Zilberman, D., 2008. The economics of biofuel policy and biotechnology. Journal of Agricultural & Food Industrial Organization 6 (2). Article 8.

Khanna, M., Crago, C., 2012. Measuring indirect land use change with biofuels: implications for policy. Annual Reviews of Resource Economics 4, 161−184.

Mekonnen, M.M., Hoekstra, A.Y., 2010. The green, blue and grey water footprint of crops and derived crop products. In: Volume 1: Main Report. Research Report Series No. 47. UNESCO-IHE, Institute for Water Education. http://temp.waterfootprint.org/Reports/Report47-WaterFootprintCrops-Vol1.pdf.

United State Department of Agriculture (USDA), 2010. EU Annual Biofuels Report 2010. GAIN Report No. NL0019. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-27_6-11-2010.pdf.

United States Department of Agriculture (USDA), 2014. EU-28 Biofuels Annual 2014. GAIN Report Number: NL4025. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_7-3-2014.pdf.

de Vries, S.C., van de Ven, G.W.J., van Ittersum, M.K., Giller, K.E., 2010. Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques. Biomass and Bioenergy 34, 588−601.

Zilberman, D., Hochman, G., Rajagopal, D., 2011. Indirect land use change: a second best solution to a first class problem. AgBioForum 13 (4).