AGRINERGY

Background note

Technologies and pathways of bioenergy production

Geert Woltjer, Marie Guliet, Floor Brouwer, Peter Nowicki
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Introduction

Bioenergy is high on the political agenda at the moment, and the views on environmental benefits differ a lot, especially on biofuels production. Optimistic views are based on assumptions about fast technological change, both in agriculture and in biofuel conversion (see for example Refuel, 2008), while less optimistic views assume slower technological change in agriculture and less potential for bioenergy (see for example Eickhout et al, 2008; Doornbosch and Steenblik, 2007).

For this reason, it is important to understand the variety of options available for producing power, heat and transport fuels from biomass, as the technology chosen will have implications on costs, carbon mitigation potential, and environmental quality. It is beyond the scope of this background note to provide detailed technical descriptions of each technology and its many variants that may exist.

Background of biofuels policy

The evaluation of technological characteristics of biofuels depends on the aims of the biofuel use. There can be three aims distinguished:

- Energy security by reduced import dependence from a limited number of politically unstable countries
- Greenhouse gas emission reduction
- Rural development

It is obvious that one policy can accomplish more than one goal and that the way the goals are prioritized differs a lot between different interest groups and governments.

For the first aim, all technologies that reduce fossil use and distribute potential suppliers over the world are useful. For the second aim reduction in energy use is useful, but when alternative energy carriers are evaluated the net greenhouse balance is important. For the third aim only options that increase rural activities are useful. For all options non-biofuel technologies may be relevant.

In analyzing the pathways for biofuels technologies, it is important to be aware of the combination of goals that is relevant for the policies and to evaluate the pathways on its efficiency to reach those goals.

EU-policy has not only set rough goals about energy efficiency and greenhouse gas reductions, but also explicit targets for renewable energy use (20% in 2020) and the share of biofuels in total transport fuels (10% in 2020). Subsidies, tax exemptions, and blending requirements have been introduced in Europe, the US and a lot of other countries.

Pathways for bio-energy use

Already in prehistoric times bioenergy was used, especially by burning. Even now most bioenergy is used in traditional ways in developing countries. Modern biofuel use distinguishes itself from traditional biofuel use by its higher efficiency in burning, or its transformation into liquids or gas that can be used for transport or be infused into the natural gas distribution grid. The main use of biofuels is for transport, electricity and heating/cooling.

Biofuels for transport

For transport biofuels a distinction can be made between first and second generation biofuels, where first generation biofuels can currently be produced on a large scale, while second generation biofuels are still in an experimental phase.

First generation biofuels for transport

The first generation biofuels for transport consist only of agricultural products, where only part of the plant is used. They are already on the market in considerable amounts. Typical first generation biofuels are sugarcane ethanol, starch or corn based ethanol, biodiesel, and Pure Plant Oil (PPO). The feedstock for producing 1st-generation biofuels either consists of sugar-, starch- and oil-bearing crops that in most cases can also be used as food and feed. Small shares of first generation biofuels can be blended with petroleum-based fuels without the necessity to change the engines of the cars and without adjustments in infrastructures. When larger shares are required, flexible fuel vehicles are needed and the fuel has to be supplied through a separate supply chain that can be integrated in the current infrastructure.

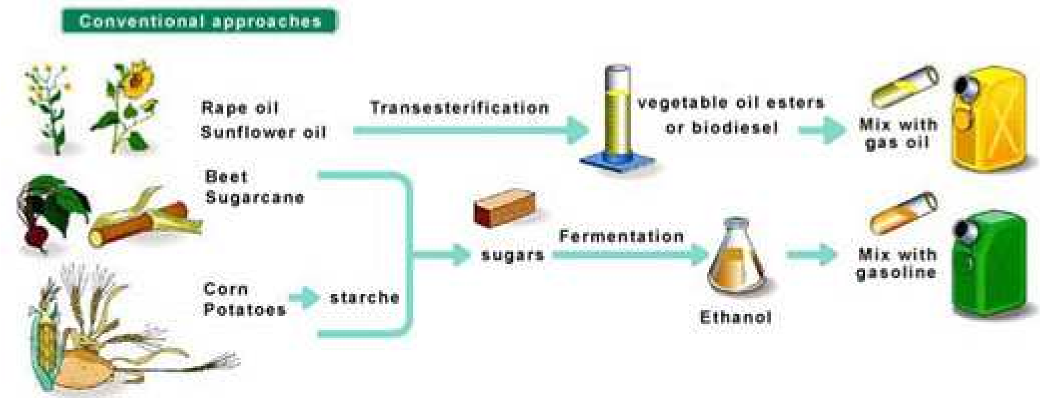


Figure 1: 1st generation biofuels pathways

Figure 1 shows the first generation biofuels pathways. Tables 1 and 2 show an overview of some characteristics of some of these feedstocks per ha, while tables 3 and 4 provide some data about production cost of first generation bioethanol and biodiesel. Because the production cost of agricultural products depends also on the crude oil price, and an increase in the use of biofuels implies a further increase in agricultural prices, while also other factors like the fast demand growth of meat and milk increase agricultural prices, information about costs provides only a rough indication of long-term prospects. In order to analyze the long term effects information about production technologies have to be incorporated into a general equilibrium model that also takes the effects of land, nutrient and water scarcity into account. Such a model is not available at the moment.

Table 1. Land and water intensity of potential sources for bioethanol (Rajagopal and Zilbermann, 2007)

Ethanol feedstock	Global acreage (million hectares)*	Water required mm/yr (low)**	Water required mm/yr (high)**	Crop yield (tonnes per hectare)*	Ethanol conversion efficiency (litre/ton)***	Gasoline equivalent ethanol yield (litre/hec)	Ethanol yield per unit of water (lit/mm)	Growing season (months)
Wheat	215	450	650	2.8	340	600	1.09	4-5 months
Maize	145	500	800	4.9	400	450	0.69	4-5 months
Sorghum	45	450	650	1.3	390	450	0.82	4-5 months
Sugarcane	20	1500	2500	70	70	3300	1.65	10- 12 month
Sugar beet	5.4	550	750	100	110	7370	11.34	5-6 months
Sweet Sorghum	insig.	450	650	40	70	1900	3.45	4-5 months
Bagasse*	na	na	na	18.9	280	3550	na	na

* estimates that are typically cited, na - data not available or not applicable, insig. - not significant

* data from FAO online statistical database

** data from FAO crop management database http://www.fao.org/ag/AGL/AGLW/watermanagement/default.stm

*** data from various sources

Table 2. Land and water intensity of potential sources for biodiesel (Rajagopal and Zilberman, 2007)

Oil seed crops	Oil content as % of seed wt	Water required mm/yr (low)	Water required mm/yr (high)	Trees per hectare	Average Crop yield kg per hectare	Average oil yield in kg per hectare	Oil yield per unit of water (kg/mm)	Time to full maturity	Useful life (years)
Coconut	70%	600	1200	100	na	4500	5.00	5 to 10 years	50
Oil palm	80%	1800	2500	150	na	5000	2.33	10 to 12 years	25
Groundnut	50%	400	500	na	1015	508	1.13	100 to 120 days	na
Rapeseed	40%	350	450	na	830	332	0.83	120 to 150 days	na
Castor	45%	500	650	na	1100	495	0.86	150 to 280 days	na
Sunflower	40%	600	750	na	540	216	0.32	100 to 120 days	na
Soybean	18%	450	700	na	1105	199	0.35	100 to 150 days	na
Jatropha*	30%	150	300	2000	2000	600	2.67	3 to 4 years	20
Pongamia*	30%	150	300	1000	5000	1500	6.67	6 to 8 years	25

* crops not commercially grown, calculations are based on estimatesestimates that are typically cited

Table 3. Production cost of bioethanol and biodiesel in dollar per litre (source: OECD, 2006)

	Bioethanol			Biodiesel
	Wheat	Maize	Sugar cane/beet	
USA	0.545	0.289		0.549
Canada	0.563	0.335		0.455
EU-15	0.573	0.448	0.560	0.607
Poland	0.530	0.337	0.546	0.725
Brazil			0.219	0.568

Second generation biofuels for transport

Although there is general agreement that first generation biofuel production is not very efficient from the perspective of greenhouse gas reduction, some people are much more optimistic about second generation biofuels (REFUEL, 2008). These are made from ligno-cellulosic materials including urban waste, agricultural and forest residues and woody crops specifically for biofuels.

There are two pathways to transfer lingo-cellulose into biofuel: first, the bio-chemical pathway, i.e. fermentation; second the thermo-chemical pathway, i.e. pyrolysis (the decomposition of organic materials by heating without using oxygen) or gasification. Methanol created by gasification can be directly used in specialised car engines, or converted into liquids through a Fischer-Tropsch conversion process that is already used to convert natural gas into liquid fuels.

Table 4. Second generation biofuel pathways. Source: Biofuels in the European Union, a vision for 2030 and beyond", Final draft report of the research advisory Council, 14/03/2006

Second generation biofuels			
Biofuel type	Specific name	Biomass feedstock	Production process
Bioethanol	Cellulosic bioethanol	Lignocellulosic material	Advanced hydrolysis & fermentation
Synthetic biofuels	Biomass-to-liquids (BTL) Fischer-Tropsch (FT) diesel Synthetic (bio)diesel Biomethanol Heavier (mixed) alcohols Biodimethylether (Bio-DME)	Lignocellulosic material	Gasification & synthesis
Biodiesel (hybrid between 1st and 2nd generation)	NExBTL	Vegetable oils and animal fat	Hydrogenation (refining)
Biogas	SNG (Synthetic Natural Gas)	Lignocellulosic material	Gasification & synthesis
Biohydrogen		Lignocellulosic material	Gasification & synthesis or Biological process

Second generation biodiesel can be blended with petroleum-based diesel without requiring different engines, and can be distributed through existing infrastructure. Second generation gas, methanol or ethanol require a separate distribution infrastructure and different car engines. The production of second-generation biofuels is currently not possible at a commercial scale.

Because the full plant can be used for second generation biofuels, it has significantly higher energy yields per hectare than first generation feedstocks. For example, energy yields per hectare of cereals would increase by 30%-40% if the straw and the grain would be used. One of the highest yielding energy crops is maize if the whole plant is used. Thus less area is needed to produce the same amount of energy. But in comparing final energy efficiency it is important to be aware that some side products of first generation biofuels that are used as animal feed have to be produced in some way and therefore also require land. When this effect is taken into account, it may be that the hectare-efficiency of second generation biofuels is not much higher than that of first generation biofuels (Eickhout et al, 2008). So, we have to be very careful not to be overly optimistic about second generation biofuels.

Second generation biofuels promises to have another advantage: there are suggestions that it can be grown on land that can not be used for food production. This is because much more plants (i.e. coppice, willows, etc.) are suitable for energy than for food production. Although this may be true for some marginal lands, it is not clear how much production can be accomplished in this way (Eickhout et al, 2008). To the extent that this is possible, land competition would be much less.

Second generation biofuels have certainly high investment cost (300 M$ for a 100,000 t/year BTL plant against 90 M$ for a 160,000 t/year ethanol plant). This also implications for the short term price elasticity of supply: second generation plants have low variable costs compared with fixed costs, and therefore will always produce at full capacity, independent of price. While for example in Brazil ethanol production can adjust to the crude oil price relative to the sugar price, this is not the case for second generation biofuels.

Gasification with Fischer-Tropsch biogas to liquid transformation requires large scale production to become profitable, implying that feedstock has to be transported from long distances. This transport requires also energy, reducing the second generation efficiency. Furthermore, as far as the goal of biofuels policy is rural development, it is much less probable that the second generation biofuels boost the rural economies.

What remains a useful exercise is the use of waste products, including animal waste and slaughtering materials, for bioenergy production (COM, 2007a). This seems to be for free, but also here we have to ask if it is wise to transform these feedstock into transport fuels instead of using them for electricity and heat production.

In summary, second generation transport biofuels may be more promising than first generation biofuels, but this is far from certain. In evaluating the efficiency of second generation biofuels compared with first generation biofuels, the value of the side products of first generation biofuels have also be taken into account. At this moment second generation biofuels can not be produced at a commercial scale.

Heating and electricity

Heating and electricity production can use many feedstocks. The first technology is just burning the feedstocks. Industrial and municipal waste, forestry and woody crops can be used as feedstock. Small scale burning of woody pellets can reach very high efficiencies, and is widely applied in Sweden. But it requires clean feedstocks, excluding waste products as a possible feedstock. For electricity production co-firing of biofuels is possible at the moment, but it requires clean biofuels and has a relatively low efficiency. If heating and electricity production are combined in one factory, efficiency is much higher. However, in order to use heat efficiently, it is required that production is relatively small scale and in the neighbourhood of people who can use the heat. This is an advantage for rural development goals compared with Fischer Tropsch conversion into transport biofuels.

Gasification provides another opportunity to use waste products, but also all other types of products. It can be produced on a relatively small scale, and the produced gas may be entered into the gas grid, used for electricity and heat production, or used as a fuel for transport. Bündnis 90 et al (2007) suggest that Europe is able to replace all Russian gas imports by biogas production. So, it seems possible to reduce imported gas dependency, although the costs of doing this have to be calculated.

Figure 1 Pathways for biofuels production (source: Biomass Normandie)

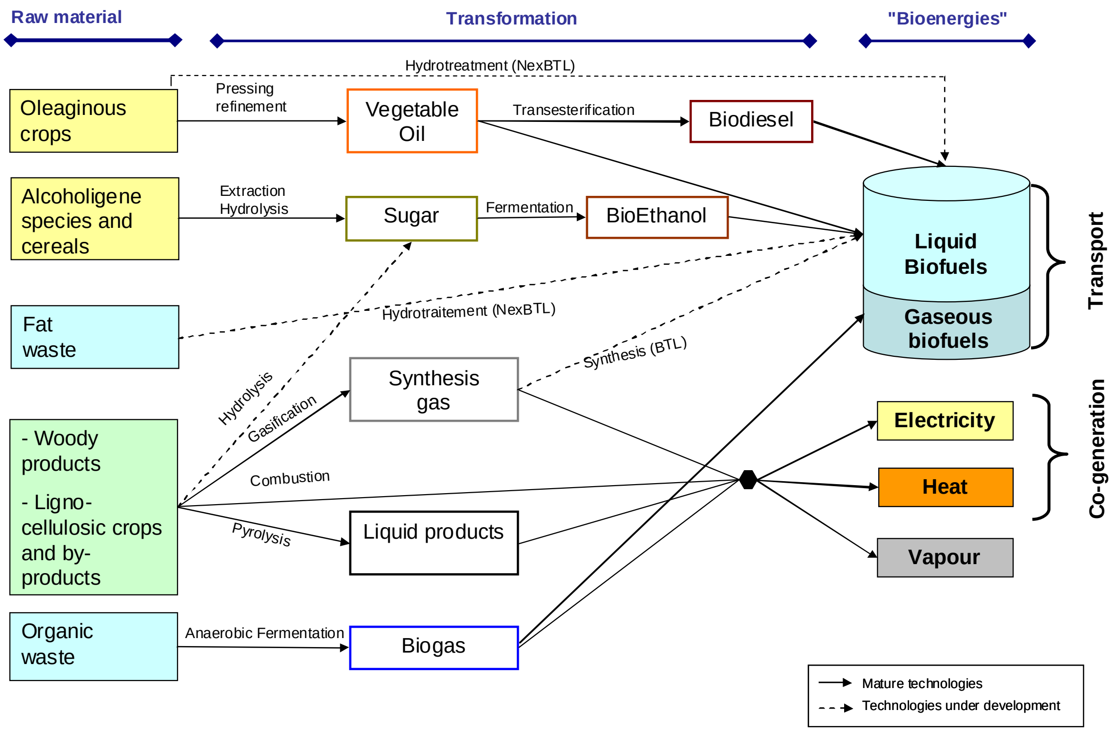
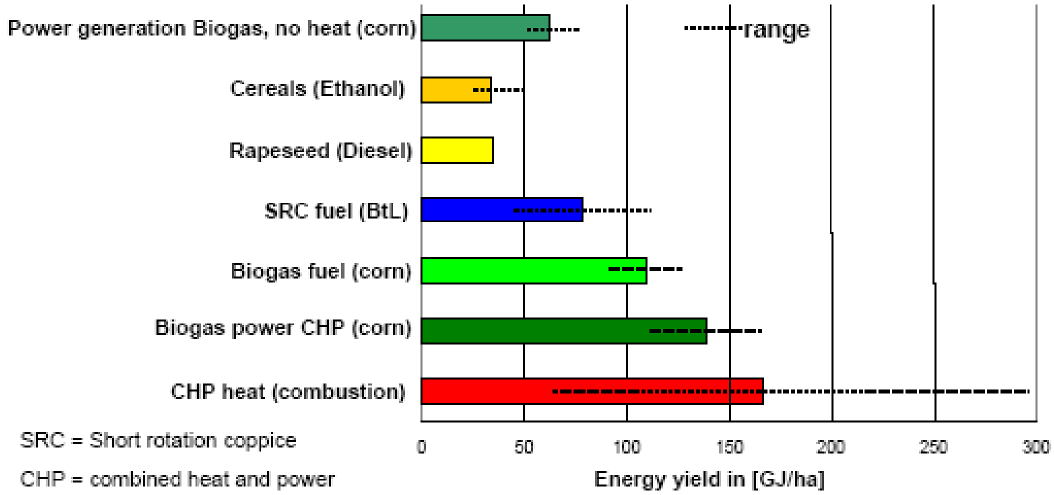


Figure 1 summarizes the main pathways to produce bioenergy, while Figure 2 summarizes the efficiency defined as energy yield per hectare for different technologies. Figure 2 shows that combustion of bio-feedstocks remains the most efficient way, followed by biogas production.

Figure 2. Energy yield per hectare (SRU, 2007; Doyle, 2007)



Future developments

In order to increase share of bioenergy in the future EU's energy mix, competing uses (food, feed, fibre, chemicals and energy) must be taken into consideration, and biomass production for energy has to be as efficient as possible in order to minimise the competition for land. Therefore, future developments are focusing on efficient and sustainable production paths and optimized uses of biomass resources, such as:

- Improving existing conversion technologies: Research programs are focusing on improving the energy and therefore carbon balance of existing technologies, through innovative processes for biomass conversion and fractionation of products (new developments in the areas of catalytic and separation processes, such as membranes, new adsorbents, ionic liquids …).
- Production of ethanol and ethanol derivatives from cellulosic biomass: Further progress is required to bring conversion processes of cellulose and hemicellulose into alcohol to the market. These include more efficient biochemical systems (new enzymes, yeasts), innovative fractionation and purification processes and efficient uses of co-products, with optimal energy integration. Additionally, the flexibility of conversion plants has to be improved in order to enable conversion of a broad range of lignocellulosic feedstock.
- Production of synthetic fuels through gasification: A wide range of biomass feedstock can be used to produce synthetic fuels (particularly, the conversion of lignocellulosic biomass seems attractive as a medium to long term prospect for producing large quantity of biofuels). R&D is ongoing, and technical innovations are needed to reduce the costs, to enhance the reliability of the technologies, achieve better energy integration and improve the carbon balance. New developments are also ongoing for transforming the biomass into a liquid "biocrude", which can be further refined, used for energy production or sent to a gasifier.

- Development of integrated refining concepts: New integrated refining schemes. Integration of new biorefineries with existing industrial complexes is examined as a way to reduce total capital cost and lower the cost of the end products.

Figure 3: Integrated biorefinery complex (source Biofuels Research Advisory Council,2006)

This optimal integration takes into account different possibilities:

- Production of a wide range of fuels and by-products from diverse lignocellulosic feedstock, whereas presently biomass conversion units are oriented mainly towards a single product (ethanol, FAME);
- Integration, in the same "biorefinery", of biochemical and thermochemical transformation stages;
- Optimal integration of oil and biomass refining sections to enable (i) the biochemical section to use hydrogen or low-grade heat from the oil refining section and (ii) the fractions produced in the biochemical section to be sent to the oil refining section;
- Optimal integration with traditional production facilities when appropriate, e.g. pulp and paper mills, sugar factories, oil mills;
- Co-processing in the same complex of oil, biomass, and possibly also coal, lignite, natural gas and biogas;
- Gasification of black liquor at pulp mills, with subsequent synthesis to fuels/chemicals, is a very promising option.

All these development trends are based on implementation of large processing units consuming important quantities of biomass. However, as outlined by the Biofuels Research Advisory Council (2006) "…agriculture and forest-derived material must be processed on a decentralised basis to avoid uneconomic shipping costs. Due to the bulky nature of biomass, road transportation is expensive relative to the value of the product and affects carbon and energy balances. Ideally feedstock will be sourced close to end uses…".

This gives an indication of the current bias in biofuels policy. It is mainly focused on transport fuels, followed by electricity production, while heat has a very low priority. In many cases energy efficiency can reach very high levels in heat production. For example, if 100toe woody biomass is converted into second generation biodiesel (40% energy efficiency), then it saves about 40 toe fossil diesel. If the same biomass is used in a heat boiler (80% efficiency), then it replaces 89 toe “diesel” in fossil fuels (AEBIOM, 2006). While stand-alone electricity production in large scale biofuels installations has low efficiencies, cogeneration of electricity and district heating is also a relatively efficient way of using biofuels, with efficiencies above 70%. And co-firing in current large scale electricity production plants may generate efficiencies up to 90% ((IEA, 2007). These CHP plants are much smaller than electricity production sites, because heat can not be transported very far, and require a local community in the neighbourhood. This may be an advantage from the perspective of rural development.

Life cycle assessment of biofuels

In order to calculate the net benefits for society for each biofuel it is important to evaluate the complete life cycle of the production process. But it is extremely difficult to get accurate estimates.

Figure 4. Greenhouse gasses and environmental impacts of biofuels as percentage of those for fossil petrol (Zah, 2007)

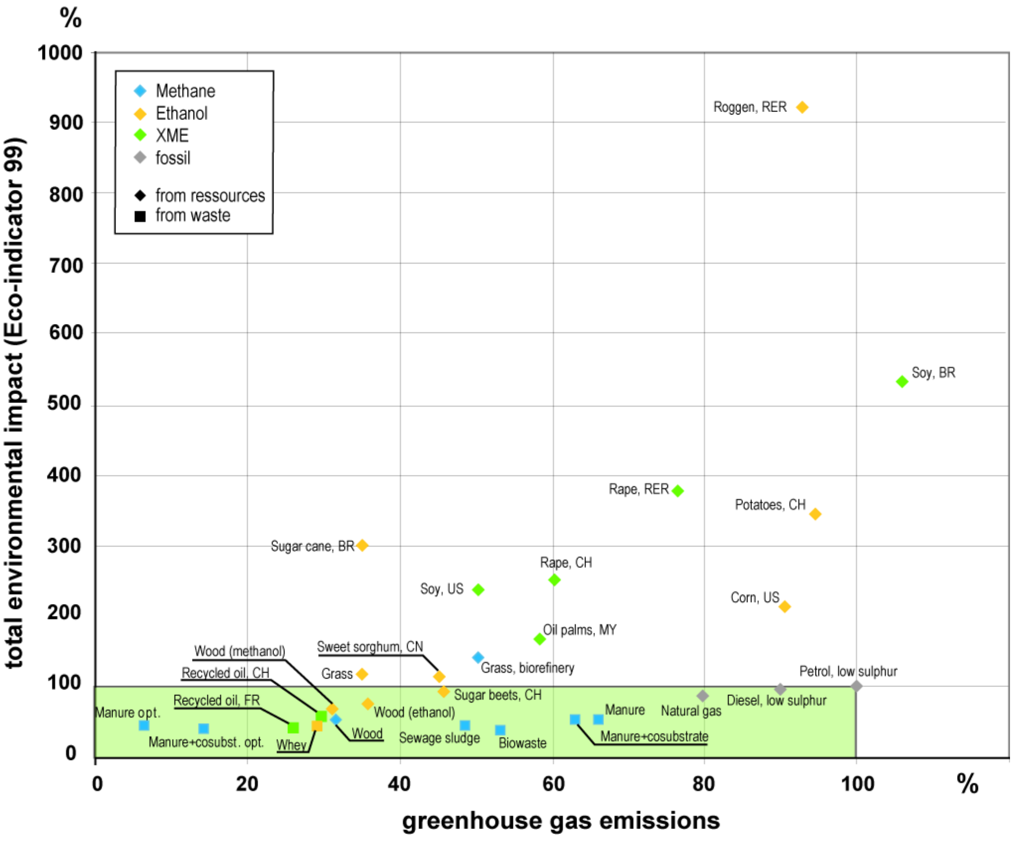


Figure 4 provides an attempt to evaluate the environmental impact of different biofuels. It shows a lot of combinations, where production costs may differ a lot. But these data have a large range of uncertainty, and therefore will be difficult to put into formal policy rules. Furthermore, indirect effects on land use are not included. So, if food production is replaced by biofuel production, the effects on the new lands are not included.

Current biofuel policies and technology choice

The increase in biofuel use is mainly driven by biofuel policies, although in some regions biofuel production is profitable at current crude oil prices. Current biofuel policies are a combination of taxes, subsidies, protection, blending requirements and environmental standards and regulations. The question arises how rational these biofuel policies are from an economic point of view.

Table 5. Possible impacts of policies on policy targets (Rajagopal and Zilberman, 2007)

Instrument	Oil use reduction	GHG reduction	Farm income	Ethanol producers	Consumer surplus (Food)	Consumer surplus (Energy)	Govt. Budget
Energy and Fuel Policies							
Biofuel Tax Credit	+	<>	+	+	-	<>	-
Biofuel Mandate	+	<>	+	+	-	-	<>
Carbon/Gasoline Tax	+	+	<>	<>	<>	-	+
Efficiency Standard	+	+	<>	<>	<>	+	<>
Vehicle subsidy	<>	<>	<>	<>	<>	<>	-
Ag and Trade Policies							
Price Support	+	<>	+	<>	+	+	-
Acreage Control	<>	<>	+	-	-	-	-
Import Tariff	+	<>	+	+	-	-	+
Export Subsidy	<>	<>	+	+	-	-	-
Export Quota	+	<>	-	+	+	+	<>
Legend	+	+ve impact	<>	uncertain	-	-ve impact	

The different rationales for biofuels policy have different implications. Table 5 summarizes the view of the Rajagopal and Zilberman (2007) on the efficiency of different policy instruments. The discussion below will be a little bit more general. First, for energy security, the best solution would be to focus on a reduction of energy dependency in combination with storing sufficient reserves for calamities. From an economic point of view all alternatives to save on fossil gas and oil should be on the same foot. If it is more efficient to save fossil oil through the use of more efficient cars or driving fewer kilometres, or the introduction of hydrogen or electric cars, the social benefit is the same as when this fossil oil is saved through an increase in the share of biofuels. In current political practice all these types of fuel saving are handled differently, and the implicit or explicit subsidies can be very high.

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Second, for greenhouse gas reduction the criterion for success is completely different from that for energy security. The evaluation of biofuels not only requires a life cycle evaluation of the biofuels production process from well to wheel with respect to greenhouse gasses, but also the inclusion of indirect effects of the carbon deficit that may be related with land use change and possible shifts of agricultural production as a consequence of biofuels production. And if the environmental effect of climate change is taken into account, it seems reasonable to also include other externalities of the decision to produce energy with biofuels: other environmental consequences, poverty, food security, biodiversity, social cohesion. This makes biofuels policy very complicated.

If greenhouse gas emissions would be the main reason behind biofuels policy, it does not seem very rational to have a separate policy for transport. Even worse, the use of biofuels for the production of heat or the combined production of heat and electricity is much more efficient than the use of biofuels in transport. So, it is obvious that there is more behind the biofuels policy than climate policy.

Third, finding an outlet for excess supply of agricultural products seems to be an important background of the current biofuels policies. The biofuels directives and subsidies provide direct incentives to use more biofuels in transport, and this requires agricultural land and for the first generation also agricultural products. The current rise in agricultural prices is partly caused by the extra demand for biofuels and improves the agricultural perspectives. It makes some marginal land profitable again, and reduces the need for subsidies to keep this land into use. This has some social advantages and gives sometimes even biodiversity improvements. Woody biofuels give more perspectives for this, and there are suggestions that in some regions with degraded lands biodiversity may improve if biofuels are produced. But to the extent that this is true, it requires very careful spatial policy to prevent that the net effect is negative.

As far as biofuels policy is guided by agricultural policy perspectives, it seems doubtful if biofuels are the best way to reach the goals of agricultural policy. If rural agricultural development would be the purpose of the biofuels policy, then it seems much more efficient to subsidize the regions involved directly, and decide what product can be produced most efficiently in that region. The biofuels policy distorts the information about efficiency.

One of the possible advantages of subsidizing currently inefficient technologies may be that learning by doing improves the production technology. Regretfully, the opportunities for technological change in first generation biofuels seem to be limited. Although a lot of subsidies are focussed on production of biofuels, the main externalities are in new technology development and large-scale commercial introduction, not in technology use that is the main focus of current policies.

The development of new technologies requires high investments in Research and Development, high costs for initial implementation and increasing cost reductions through learning by doing and competition between suppliers of investment goods. All these activities generate positive externalities that may be an argument for subsidies. However, the problem with subsidies for high potential technological pathways is that government has to decide about which pathways have high potential. Targeted subsidies may be partly in the wrong direction. Nevertheless,

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money on Research and Development and the introduction of promising innovative techniques may be better spend than on inefficiency generating non-discriminating production subsidies.

Conclusion

Current biofuels policy is focused on a limited number of technologies and discriminates against other technologies that may solve the problem. Mandatory biofuel blending requirements do not help to search for energy saving or electricity use in transport, although this may be accomplished through other measures.

Mandatory biofuel requirements will be combined with certification schemes, but this does stimulate to use the cheapest types of biofuels that are allowed for, not the most efficient ones. If second generation biofuels are counted double (which can only be defended from the perspective of greenhouse gas savings, but not from an energy safety perspective and probably also not from a rural development perspective) then there are no opportunities for perhaps environmentally more efficient first generation biofuels to compete with, nor using heat and electricity production to substitute for carbon fuels.

The problem with the current knowledge about life cycle evaluations of biofuels, including cost and environmental externalities, is the large range in outcomes of those evaluations depending on the method used. Furthermore, environmental effects depend very much on the characteristics of the land that is used, management practices and indirect effects on land use. Therefore, effective certification will be very difficult.

Key questions for further discussion

- What are the perspectives for second generation biofuels for transport?

- How can a balanced portfolio be reached between different uses of bioenergy, i.e. first versus second generation transport biofuels, co-firing, gas production combined heating and electricity, and heating.

- To what extent do current policy measures give different instruments to reach the policy objectives energy security, greenhouse gas reduction and rural development the same chance to reach ?

- To what extent is it possible to put efficiency incentives into policy measures to promote bioenergy? Can LCA be made operational in such a way that it can be used in policy?

- How is biofuels policy related with other policies, like the Common Agricultural Policy?

- What should be the role of subsidies targeted on development of new technological pathways?

- How to create a balance between short term available technologies and long term technologies that may be more efficient but require a system change?

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