Understanding value chains in industrial biotechnology

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Actual and future value chains regarding the industrial bioeconomy show that OECD countries will continue until 2050, at least, to be net importers of fossil fuels and also of biomass. In order to see a flourishing industrial bioeconomy in Europe, there is a need for competitive sources of biomass, including agricultural and forestry residues and waste materials. In principle, it should be easy to substitute local production in Europe to imports, given the size of demand. However, relative prices of fossil fuels versus renewable biomass will be a key to the growth of bio-sourced products in the European market. At present the competition is unwinnable: the fossil industries have a century of a head start and they still receive enormous subsidies. Creating a level playing field should be a pre-requisite for Europe.

From a public policy perspective, creating a level playing field is both a high priority and a legitimate goal since it does not imply any selection by a government of a given technology pathway. The "technology neutral" requirement for public policies would be met while enforcing a level playing field that would still open the door for new entrants and particularly a circular and industrial bioeconomy.

Introduction

The message that the 2013 OECD-WTO-UNCTAD report to G20 Leaders, *Implications of Global Value Chains for Trade, Investment, Development and Jobs* had for the G20 Leaders was clear: global value chains reflect 21st century production and provide potential mechanisms for all countries to improve income, employment, and productivity. Open markets are crucial, but alone they are insufficient; global value chains (GVCs) also need to be complemented with appropriate policy frameworks that allow countries and firms to capitalise on their existing productive capacities and spill-over benefits from foreign investment, knowledge, and innovations (OECD – WTO – World Bank Group, 2014).

However, if the drivers for the development of industrial biotechnology are analysed, it is clear that much of the policy being developed favours local supply chains, and more local value chains. The policy goals for industrial biotechnology are among the most important issues of our times: climate change mitigation, energy security, food security. For OECD countries there are other drivers, such as a need to reindustrialise (and thus create new jobs and growth), keeping their vital chemicals sectors competitive, and rural regeneration. Waste treatment and disposal is a major burden on many countries, developed and developing (OECD, 2013a).

There are more country-specific, localised drivers. For example, in heavily-forested countries with a history of pulp and paper production, some are currently suffering from decreased demand in some sectors (e.g. newsprint), rising costs and increased competition from emerging countries (de Jong and Jungmeier, 2015). Therefore, for a whole range of reasons, industrial biotechnology is emerging as a sector, and it goes way beyond biotechnology.

The contradiction created will be obvious. As increasingly GVCs are seen as a way to generate economic growth, industrial biotechnology seems more suited to regional and national value chains as the model seems to dictate distributed manufacturing in small-scale, often rural biorefineries. However, the outputs of biorefineries are global products, in many cases drop-in fuels, chemicals, plastics and textiles as replacements for fossil-derived equivalents. This is a major change from 'business as usual'. It is a way for industrial nations to claim back jobs lost through capacity building in Asian manufacturing and to save high-skill jobs in the ailing OECD nations' chemicals sector. But it is also an opportunity for developing nations to make use of large stores of biomass at the same time as making the value-added, bio-based industries of the future. In this way, the efforts are truly global.

However such moves will continue to be globalisation-dependent. The actual and future competitiveness of local biomass and bio-sourced products will depend upon relative prices of fossil fuels compared to the prices of agricultural or forest commodities. In the case of low relatives prices of fossil fuels (oil around USD 50, shale gas below USD 5 per BTU, coal), international trade flows of biomass might be low and the competitiveness of local biomass will be in jeopardy. Only if fossil fuel prices would be higher (around USD 80 per a barrel for crude oil) and/or a significant carbon tax (USD 50 or more) would be put in place, then bio-sourced products would start to flourish.

In the same vein, a game changer could be the end of the tax privileges of international transportation (air traffic or maritime bunkers) and/or the integration of negative externalities of international transportation. If it is not feasible to end such tax privileges under the current international governance system, then renewable fuels and biomass should be compensated in order to create a level playing field. The issue of taxation of international transportation is therefore another angle to visit international trade and understand why large quantities of woody biomass flow from west Canada to Europe (Table 1) via the Panama Canal or palm oil from Malaysia to Europe (Figure 5).

The industrial biotechnology value chain

A look at a generalised biomass value chain for industrial biotechnology will demonstrate why the bioeconomy has gone way beyond biotechnology (Figure 1). Here is an opportunity to enable the long-held desire in advanced economies to revitalise the rural environment. Over several decades agricultural efficiencies have meant the end of the vast majority of jobs in primary production. Between 1950 and 2010, the share of the US population directly involved in agricultural production has dropped from 15% to less than 2% (USDA, 2010).

Agricultural inputs

Typical agricultural inputs would be food crops (such as sugar beet and sugar cane), and various low-value residues such as wheat and barley straw for refining in cellulosic biorefineries. A relatively recent development is energy crops (i.e. non-food crops that are efficient biomass forms). Brazil has developed energy cane that is believed to more than triple the productivity of ethanol production. A flagship project in Europe is the use of cardoon (a thistle) in biorefining as it contains oil, has long stalks as a source of biomass, and even the roots contain useful compounds such as inulin.

Future crops for biorefining will be genetically modified and others will be selected by using genomics data in breeding programmes. Typically traits being sought are pest resistance, but under the influence of global warming there is a considerable drive towards drought resistance

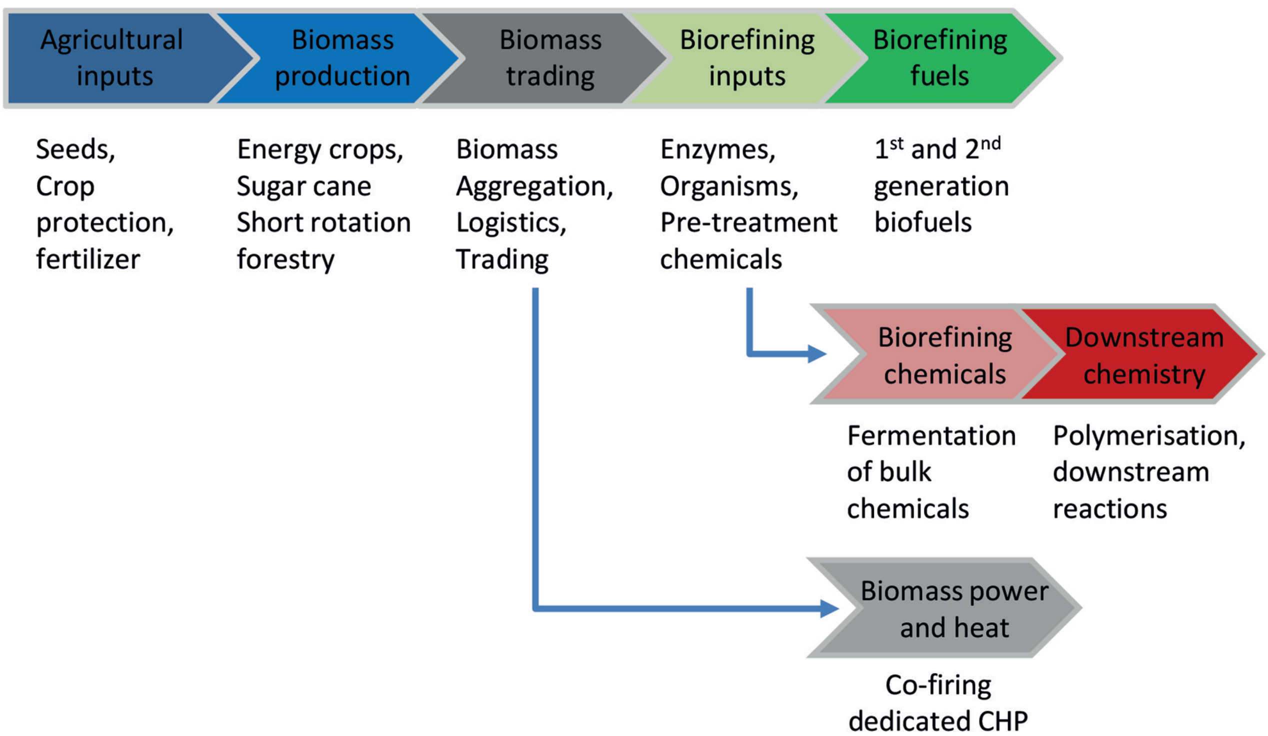

Figure 1: Generalised scheme of an industrial biotechnology value chain based on biomass.
Source: adapted from World Economic Forum (2010).

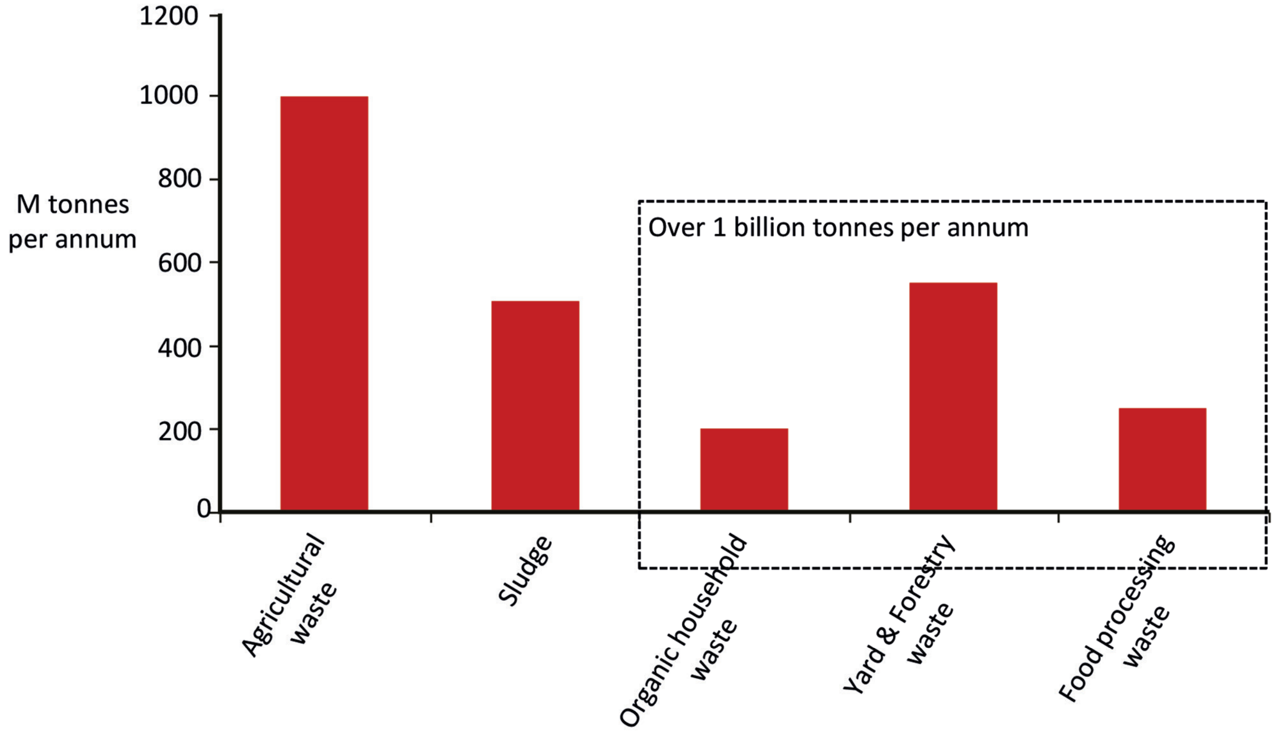

Figure 2: Waste materials that could be used in biorefining in Europe amounts to over 2 billion tonnes per annum.
Source: Fava & al. (2015).

(e.g. BLUM, 2014). There has long been interest in cereal crops that fix their own nitrogen as synthetic fertilizers have a range of negative environmental impacts and they are expensive for subsistence farmers in the developing world. Using synthetic biology, full nitrogen fixation in cereals may be about a decade away (KEASLING, 2015) but partial nitrogen fixation may be available before then (STOKSTAD, 2016).

Waste materials inputs

There are clearly very large volumes of waste materials or residues that can be used in biorefining (Figure 2). Agricultural residues such as straw may be seen as waste materials. There are large volumes of residues from forestry that can be used in biorefining. The first biorefinery converting municipal solid waste (MSW) into bio-based products opened in Edmonton, Canada. Food wastes are made in huge volumes. And the first demonstration plants that convert industrial waste gases into ethanol have been operated. In the near future a commercial biorefinery of this type utilising steel-making waste gases for fermentation will be built in Belgium.

The added value from using waste materials in the industrial biotechnology value chain is, of course, that they should be inexpensive, and, as wastes, they are inherently of no value anyway. Creating added value from these materials should be easier than using crops, but the calculations are case-specific. Waste materials have the other advantage of taking pressure off land use.

Biomass production

Growing food or energy crops for biorefining offers farmers and grain processing companies new business opportunities and markets, in addition to traditional land uses. Biomass production may offer the largest single business potential along the entire biomass value chain.

It is accepted that food security must come first, however. Brazil has realised that to keep up with demand for ethanol, more land will be required for sugar cane production. In response, in 2009, the Brazilian government launched the Agro-ecological Zoning for Sugarcane initiative (*Zoneamento Agroecológico da Cana-de Açúcar* (1)) to promote the expansion of sugarcane production in areas that are agronomically, climatically and environmentally suitable, whilst protecting sensitive ecosystems.

Biomass trading

This is possibly the most problematic stage of the biomass value chain. It calls for new 'industrial ecosystems' that join up many stakeholders if efficient supply chains are to be created. Consider that in Europe alone there are some 16 million forest owners and 14 million farm owners (HETEMÄKI, 2014). Achieving supply chain efficiencies towards large-scale production comparable to those in, say, the crude oil industry is going to be challenging in certain situations, hence an important role for decentralised small-scale production. This creates employment opportunities in haulage and logistics, for example, and may make the stimulus for research and innovation to increase the energy density of biomass. Low energy density makes the economics of long-distance transportation challen-

(1) https://www.embrapa.br/en/busca-de-produtos-processos-e-servicos/-/produto-servico/1249/zoneamento-agroecologico-da-cana-de-acucar.

ging and potentially unsustainable. And supply chains will need to be constructed with the seasonal nature of biomass in mind (GIULIANO & *al.*, 2016).

Biorefining inputs

A range of biomass pre-treatment processes are in existence and there is a drive to make them more efficient. These chemical, biological or thermal treatments are necessary to increase the availability of fermentable substrates during the actual biorefining. Themselves they create a sizeable market for products (e.g. steam explosion technologies and enzymes) and they stimulate research and innovation. A promising option for the future is consolidated bioprocessing (CBP), in which a modified microorganism is responsible for both breakdown of (ligno)cellulosic materials to fermentable sugars, and then ferments the sugars to products such as chemicals and plastics. The US Department of Energy (USDOE) endorsed the view that CBP technology is the ultimate low-cost configuration for cellulose hydrolysis and fermentation (USDOE, 2006), as it eliminates the expensive enzyme step, and reduces the number of reactors required.

Biorefining outputs and the cascading use concept

A wide range of biorefinery products can be produced, ranging from low added value (burning for heat and electricity generation) to higher added value, lower volume chemicals, materials, all the way to highest added value bio-pharmaceuticals (Figure 3). Production at a scale that can influence a market has been a major roadblock to many biofuels production routes. As a result, small, innovative bio-production companies have chosen to target high value, low volume specialty chemicals with new functionality as their first route to market. However, the vast majority of the demand is for direct drop-ins that are comparable in price or cheaper than the fossil-derived, conventional product (WEBSTER and FRANCIS, 2016).

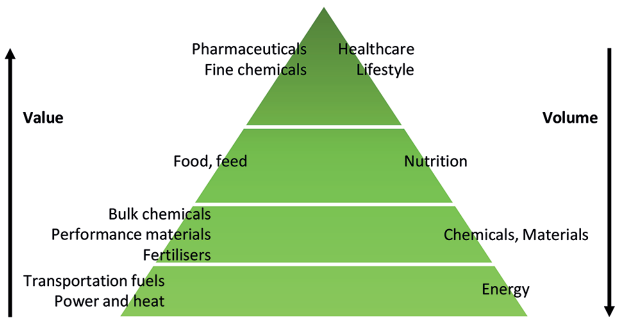

Figure 3: Biorefinery outputs span a wide range of added value products.
Source: Manninen (2016).

In the 'cascading use' concept, higher value-added materials are extracted first from biomass and only when all other avenues have been explored, the residues are used for energy purposes (KEEGAN & *al.*, 2013). This is supposed to maximise the value gained from biomass, and at the same time reduce waste, which is consistent with the circular economy [(2)]. In Europe, the cascading use concept is popular, but there is little support in policy at present.

Where is the most added value?

Carus & *al.* (2011) estimated that materials use can directly support 5-10 times more employment and 4-9 times the value-added compared with energy uses, principally due to longer, more complex supply chains for material use. In support of such claims, a bioeconomy report from Flanders (summary in English edited by Van Melkebeke, 2013) confirmed that, in Flanders, bio-based products (such as paper, wood-fibre boards, bioplastics and bio-based chemicals) have created five times more value-added (based on gross margin calculations) and ten times more employment than bioenergy. More recently Piotrowski & *al.* (2016) calculated a ratio of employment to turnover in various bioeconomy sectors (Figure 4).

This chart suggests that the job creation potential of bioenergy is low. Also the economic benefit from bioenergy is minimal (FAHD & *al.*, 2012). The economics of biofuels production are often a challenge, especially in times of low crude oil prices. The co-production of bio-based chemicals, plastics, food and feed can create the needed added value to make an industrial biotechnology process viable (IEA Bioenergy Task 42 – Biorefinery, 2012). This is the primary driver behind the so-called integrated biorefineries, where multiple feedstocks can be converted to multiple products. Bioenergy should be seen as a "*final destructive use*" of biomass, and should be generated from waste streams. For this to be possible requires a level (policy) playing field for bio-based chemicals, fuels and energy use of biomass. Large subsidies for biofuels and bioenergy systematically prevent new developments and investments in the higher value-added applications such as bio-based chemicals and materials by only supporting energy use of biomass (CARUS & al., 2014).

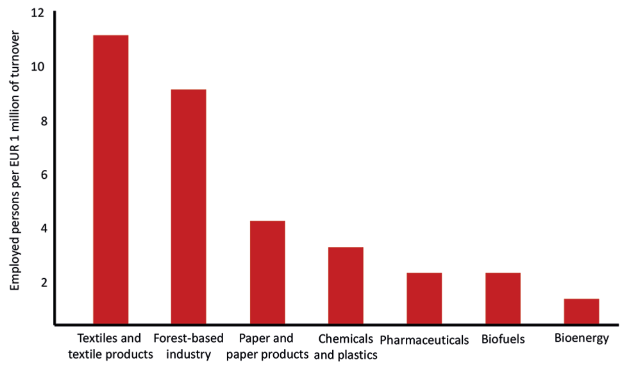

Figure 4: Employed persons per EUR million of turnover.
Source: Piotrowski & al. (2016).

Global supply and value chains

Global supply chains have been established for biomass trade in large volumes for the main purpose of electricity generation in OECD countries and regions (Figure 5). This

(2) *http://ec.europa.eu/environment/circular-economy/index_en.htm.*

Not only do all the arrow-heads point to OECD nations, but there is a significant convergence on Western Europe.

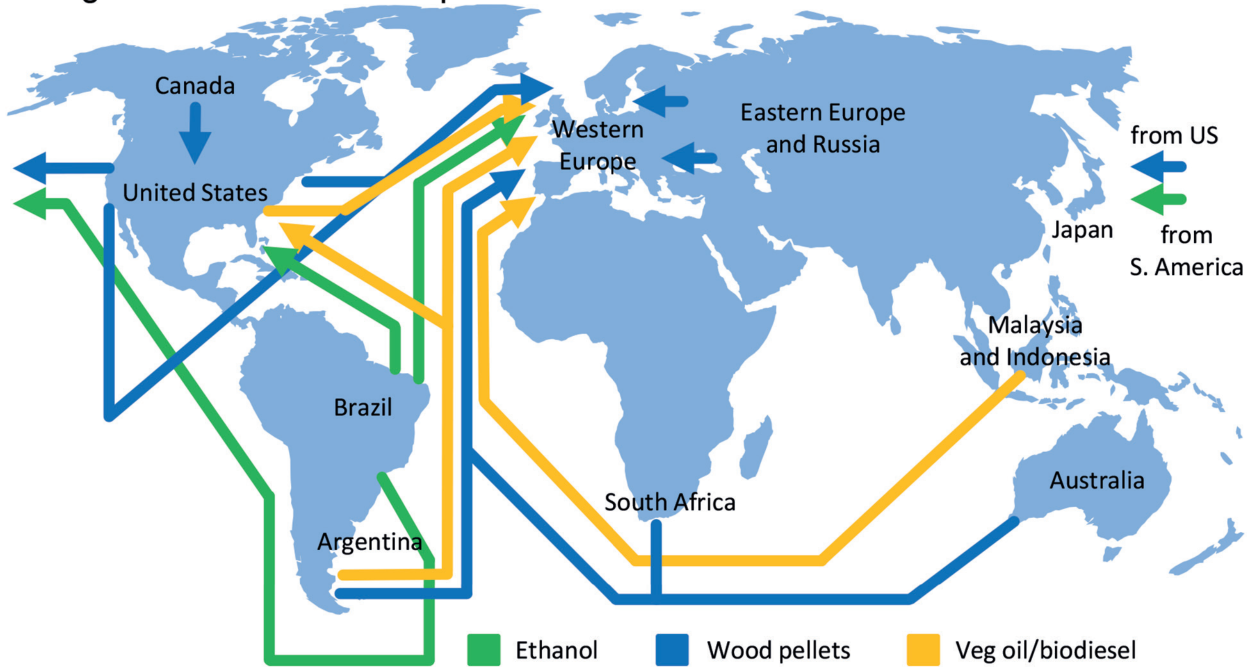

Figure 5: World biomass shipping routes in 2011.
Source: Redrawn from BP-EBI (2014).

network has been established to help countries to meet their greenhouse gas (GHG) emissions targets. However, we refer to this as global supply chains rather than value chains due to a lack of evidence that this trade in biomass creates much added value.

For OECD nations which lack biomass resources, there is the danger that bio-production fails to achieve policy goals like energy security as the dependence is simply switched from oil exporters to biomass exporters. For biomass exporting countries, relying simply on exporting raw materials would miss the opportunity to create the greater value-added bio-production industries.

For sure the volumes are enormous (Table 1). The main sources of biomass for electricity generation are wood pellets and residues from agriculture and industry [(3)]. The importance of wood pellets for large scale power generation is increasing dramatically, such that many countries have become net importers. One estimate has it that Europe will be importing 80 million tonnes of solid biomass per annum by 2020 (COCCI *& al.*, 2011).

There is, however, much greater diversity in the biomass and waste materials that could be traded internationally if the sustainability and economic conditions are right. It would be helpful to compare experiences of advanced economies with little biomass to spare with developing economies with abundant biomass. Technology transfer from the former to the latter and biomass trade from the

(3) http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/.

	Production		Consumption	
Country	**2005**	**2010**	**2005**	**2010**
Austria	440	850	305	660
Denmark	187	180	820	1600
Finland	190	253	55	213
Germany	240	1200	200	1845
Italy	240	750	290	1450
The Netherlands	110	120	487	913
Sweden	1100	1645	1480	2200
European Union	2628	9260	3835	11400

Table 1: Wood pellet production and consumption patterns in various countries (thousand tonnes).
Source: adapted from Scarlat & al. (2013).

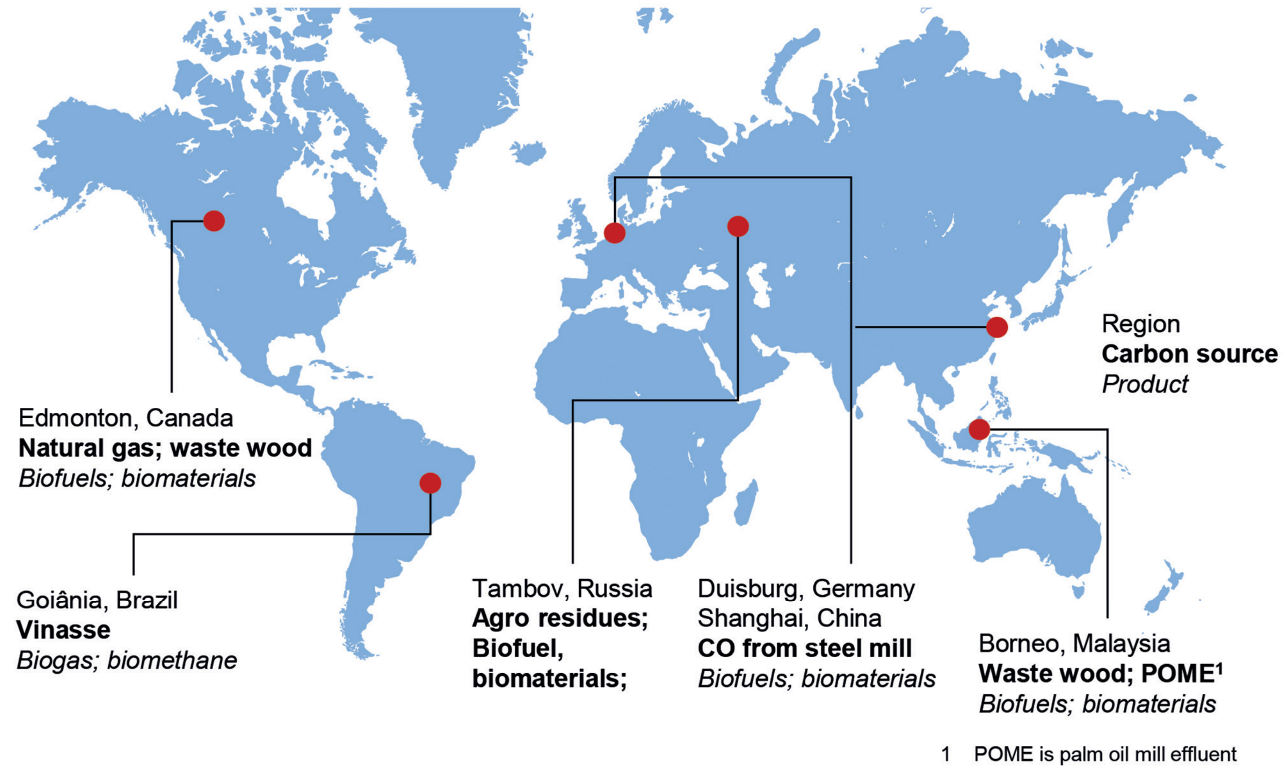

Figure 6: CLIB2021 outreach to biomass-rich regions.
Source: adapted from Kircher (2016).

latter to the former seem like an equitable way to develop a sustainable bioeconomy. The experiences of the regional cluster CLIB2021 [4] in Germany in this internationalisation are worthy of examination from a public policy point of view. CLIB2021 has been fostering relationships with biomass-rich regions of the world (Figure 6).

Future prospects for value chains: the case of Europe

Future competitiveness of the industrial bioeconomy is largely based on the relative prices of commodities on international markets. This is true when the relative prices of agricultural commodities are compared over time across continents or countries. This is equally true when it comes to competition between renewable and non-renewable fuels.

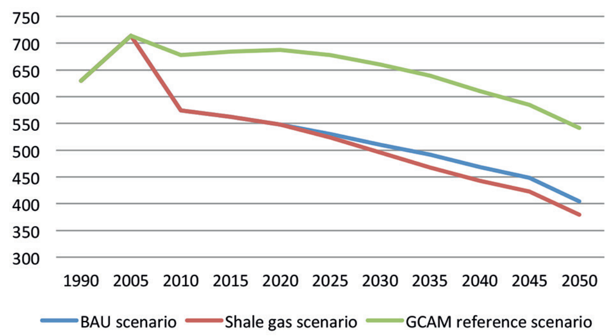

Figure 7: Primary energy consumption in Europe by 2050: Oil (Mtoe) [7].
Source: Schieb and Chelly, 2016b.

Using the Global Change Assessment Model (GCAM-BIOTECH 3.2 version), Schieb and Chelly (2016a) have shown that the European demand for oil could drop by 24% between 2005 and 2050 (Figure 7) and that coal (particularly liquefied coal) and natural gas would mostly benefit from such a substitution within the realm of fossil fuels in Europe. However, the end of the coal-fired power era is inevitable [5], with coal-fired power stations closing in many countries [6]. The strong increase in coal liquefaction would be for transportation and chemicals production.

Production of agricultural products would see an increase of 20% in oil crop production (from 30 to 36 Mt), the sugar crop would drop from 125 Mt in 2005 to 67 Mt in 2050 (Figure 8), the production of wheat would be around 127 Mt in 2050 with a 6% increase. A decline in European sugar production is also predicted by the UNFAO (BRUINSMA, 2012).

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(4) http://www.clib2021.de/en.
(5) http://www.finchandbeak.com/1157/closing-coal-plants-important-signal.htm.
(6) http://www.powermag.com/industry-in-turmoil-coal-plants-shutting-down-around-the-world/.
(7) Mtoe: mega tons of oil equivalent. The reference scenario (GCAM reference) is based on low oil (USD 45) and gas prices. The business as usual scenario (BAU scenario) is based on much higher price levels (oil at USD 80 per barrel, gas at USD 8). The shale gas scenario is a disruptive scenario which would see the production of shale gas starting in Europe from 2020. Late September 2016 saw the first batch of US shale gas arrive in the UK.

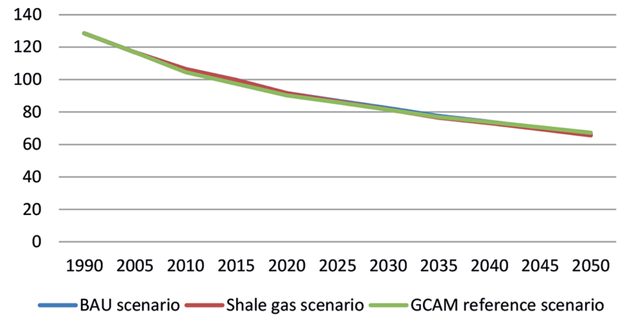

Figure 8: Sugar crop production in Europe by 2050 (Mt) [(8)].
Source: Schieb and Chelly, 2016b.

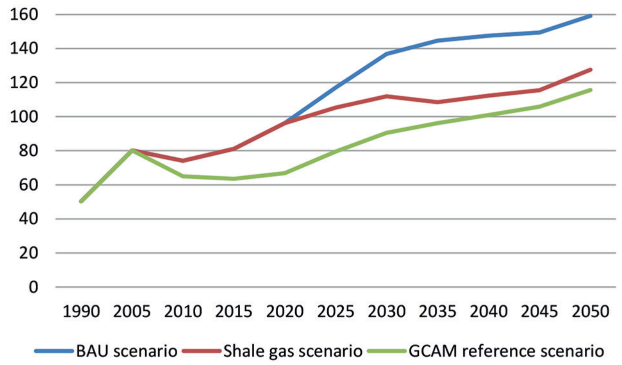

Figure 9: Total biomass consumption in Europe by 2050 (Mtoe).
Source: Schieb and Chelly, 2016b.

However, the rise in demand for biomass (Figure 9) would be such that Europe would have to import a lot of biomass since a gap of 73 to 118 Mtoe could occur by 2050. By creating demand for an export market for biomass, Europe should be alert to the possibilities of also exacerbating conditions for unsustainable practices such as soil exhaustion, illegal logging and deforestation. The first international biomass disputes have already occurred (BOSCH *& al.*, 2015), and the Netherlands government has examined the possibilities for an international biomass dispute settlement facility (TAANMAN and ENTHOVEN, 2012).

These results should not be taken as predictions and they are not inevitable. Policy measures both locally and globally, feedback loops from agricultural or industrial actors could change these prospects. What they could mean is that the role of international trade, under current or new circumstances, would be crucial for local and international value chains. The pace of growth of international trade could be derailed in the short run by a number of events such as the consequences of BREXIT, geopolitical shocks, climate change, movements of exchange rate or the role of financial actors on markets.

It is not sure that international trade agreements would change the future prospects particularly for sensitive items such as agricultural biomass. Conversely, other circumstances such as the global implementation of a carbon tax (OECD, 2016) or changes in the distortion of competition between renewable and fossil fuels would greatly change the picture.

What about the distortion of competition as an impediment to renewable fuels?

Creating a level playing field between renewable fuels and biomass with fossil fuels is a key factor in the success of an industrial bioeconomy. Incumbent suppliers of fossil fuels benefit from a long experience curve, huge

(8) Mt: million tons.

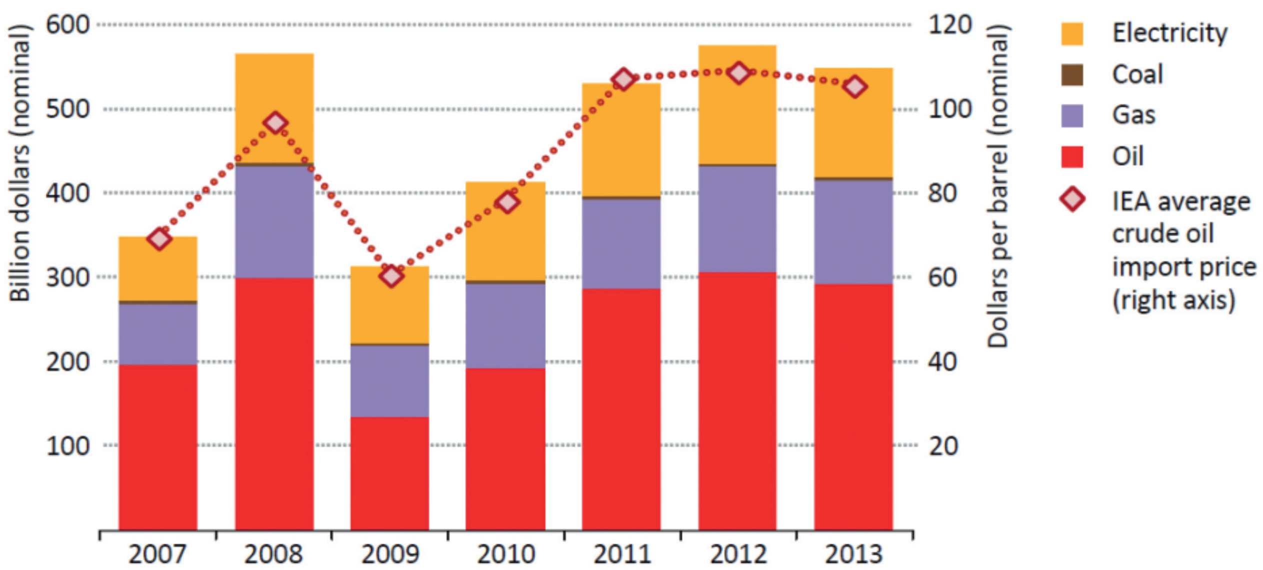

Figure 10: Estimate of subsidies to fossil fuels over the period 2007-2013. (IEA, 2014).
Source: IEA (2014).

	Transport aérien	Transport maritime	Total
Carburant(s)	Kérosène	Le DIESEL MARINE LEGER (DML) ou Essence bleue SP98 ou FUEL SOUTE	
Consommation 2012 (Mtep) (9)	6,66	2,28	8,94
Consommation 2013 (Mtep) (9)	6,6	2,1	8,7
Détaxation année 2012 (milliards EUR)	4,9	1,07	5,97
Détaxation année 2013 (milliards EUR)	4,85	0,98	5,84

Table 2 : Estimation des montants de détaxation des carburants utilisés dans le transport international en France (Schieb and Chelly, 2016a).

economies of scale from perfected processes and supply chains, amortised plants, sunk investments but also from direct or indirect subsidies.

The OECD has identified some 550 different forms of fossil fuel subsidies (to production and/or consumption) (OECD, 2013b). The IEA has estimated (Figure 10) the global amount to be at USD 548 billion in 2013 (IEA, 2014). In the OECD countries themselves fossil fuel subsidies had an aggregate value of the order of USD 55-90 billion per year over the period 2005-2011.

However, such calculations do not encompass the indirect subsidies due to the environmental footprint. Fossil energy received a staggering USD 5.3 trillion, or 6.5% of global GDP, in post-tax subsidies (that calculate the environmental cost) in 2015 (IMF, 2015). The IMF estimated that eliminating post-tax subsidies in 2015 could have raised government revenue by USD 2.9 trillion (3.6% of global GDP), cut global CO_2 emissions by more than 20%, and cut premature air pollution deaths by more than half.

One of the most damaging effects of subsidising fossil fuels is on clean energy investment. In the Middle East, more than one-third of electricity is generated using subsidised oil, accounting for nearly 2 million barrels per day. In the absence of subsidies, all of the main renewable energy technologies, as well as nuclear power, would generally be competitive with oil-fired plants in the Middle East (IEA, 2014).

In the case of France, an estimate of the direct tax losses due to the privileges of international transportation (air and sea) amounts to EUR 6 billion per year (Table 2). A global estimate could be around USD 70 billion per year.

As European countries are perhaps not in a position to change the international tax framework, then it would be possible to argue at the WTO level that subsidies to renewable fuels and biomass (or other equivalent measures) could be acceptable in order to create a level playing field between fossil fuels and renewable biomass.

Conclusions

Actual and future value chains regarding the industrial bioeconomy show that OECD countries will continue until 2050, at least, to be net importers of fossil fuels and also of biomass. Of course bio-sourced products can belong either to the market of commodities (such as for instance biofuels, bioplastics or chemical building blocks) or to the high value added niches of molecules that are used by cosmetics, medical implants, fibre materials or food ingredients. In the latter cases the volume of biomass is much lower but to be competitive the process needs to be part of a large volume integrated biorefinery, where the low margins on fuels are boosted by higher margins for chemicals.

In order to see a flourishing industrial bioeconomy in Europe, there is a need for competitive sources of biomass including agricultural and forestry residues and waste materials. In principle, it should be easy to substitute local production in Europe to imports, given the size of demand. However, relative prices of fossil fuels versus renewable biomass will be a key to the growth of bio-sourced products in the European market. At present the competition is unwinnable: the fossil industries have a century of a head start and they still receive enormous subsidies. Creating a level playing field should be a pre-requisite for Europe.

From a public policy perspective, creating a level playing field is both a high priority and a legitimate goal since it does not imply any selection by a government of a given technology pathway. The "technology neutral" requirement for public policies would be met while enforcing a level playing field that would still open the door for new

(9) Bilan énergétique de la France en 2013 : http://www.statistiques.developpement-durable.gouv.fr/.

entrants and particularly a circular and industrial bioeconomy.

Disclaimer

The opinions expressed and arguments employed herein are those of the authors and do not necessarily reflect the official views of the Organisation for Economic Cooperation and Development (OECD), or of the governments of its member countries.

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