Freight Transport and Deployment of Bioenergy in the UK

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Abstract:
Delivering energy, in the form of biomass, to a bio refinery, or to a conversion plant, plant requires transport of biomass feedstock. We examine the indirect impact on UK of freight transport mode choice through specific pathways of biomass, biomass (renewable energy) systems to supply power, heat and biofuels. These impacts arise from moving biomass feedstock. Extensive utilisation of biomass may increase freight transport services. Socially acceptable distances travelled will vary from long distances for rail to short distances for trucks. Trucks will require more energy per tonne moved versus railways. Railways, as well as ships, are capable of magnifying the market and technology potential of biomass deployment and its utilisation as railways require less energy per tonne moved in the country. Successful biomass delivery to plants will need railway capacity expansion requiring new infrastructure investment. Most biomass schemes will be 50 km distance from the farm or warehouses (supply) or bio heat plant but the demand for freight transport services has the potential to increase 1) CO_2 emissions, (2) non- CO_2 emissions, (3) accidents, (4) environmental costs (5) and social costs of UK generated biomass schemes. Some policy recommendations include the need to carefully select siting and spatial factors when designing large scale deployment of bio-energy and of biofuels. Designing an energy policy based on biomass brings new challenges since biomass may itself be freight transport intensive.

1 Introduction

This article aims to assess the extent to which freight transport poses a supply chain barrier, and an externality, for the take up of biomass in the UK. Global demand for electricity and heat as well as of motor fuel (and fossil fuels consumption of other modes of transport) is exerting pressure on fossil fuels supply and increasing greenhouse gas emissions (GHG) to 6.3 $GtCO_2$ in 2004 (IPCC, 2007), which increases the need for alternative energy sources. One solution is bioenergy from agricultural crops (in this case: miscanthus, short rotation crops, or forestry residues[1]) since these are deemed to adsorb carbon dioxide as they grow and produce lower GHG emissions than, say, conventional fuels (gasoline or diesel). Figure 1 depicts the close relationship between corn for ethanol and oil price for the case of the U.S., one of the world's largest producers of corn to ethanol.

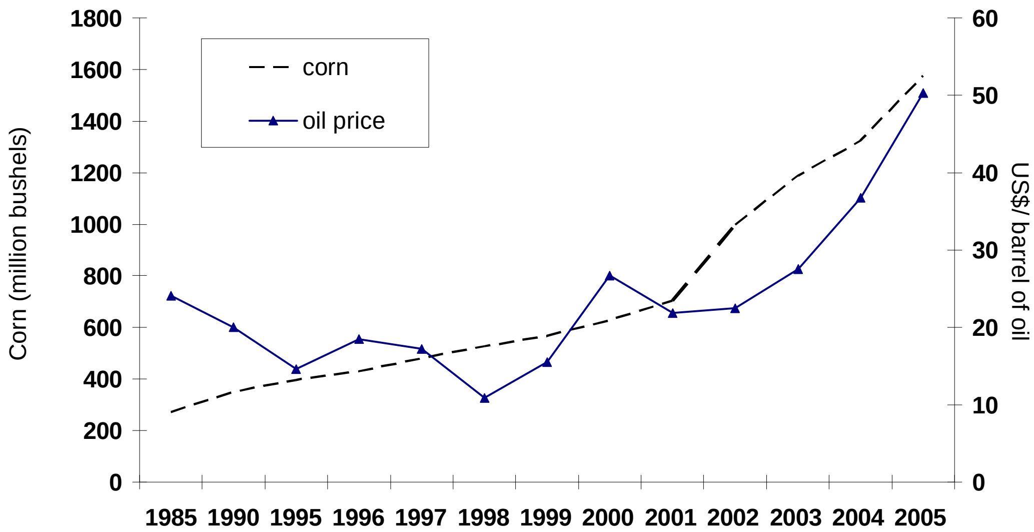


Figure 1. Oil price and corn feedstock: U.S Ethanol (U.S. EIA,(2009) and Biomass Energy Data Book (2006)

[1] These crops require less fossil fuel inputs when grown and little fertiliser; these crops do not dominate the bio energy mix for power and heat or biofuels now. These crops can be used to produce bioethanol (liquid fuels form) or methane and producer gas (in gas form). However the technology for producing fuel (cellulosic ethanol) from these sources is still expensive and in its infancy.

The UK already imports more than 80% of biomass feedstock for co-firing which brings freight transport implications, for example, it increases externalities, pollution, traffic, nationwide dependence on imports of oil and accidents. Efficient truck deliveries of biomass/biofuels deployment is key. The UK also imports bio-ethanol from Brazil and the U.S by ocean freight. Feedstock for UK biodiesel is also imported from South East Asia and other geographical regions.

The IPCC (Intergovernmental Panel of Climate Change) estimates that bio-energy could provide 15% of the world's primary energy use (IPCC, 2007). Globally the biofuels, derived from agricultural crops, industry is worth 15 bn. US$ (Stern Review, 2007) and currently about 1% of transport energy use in the world is made up by biofuels (equivalent to 20 million tonnes of petroleum). The IEA forecast a share of 7% of biofuels of world transport energy use in its World Energy Outlook (IEA, 2005).[2] The IPCC projects 25% biofuel share of global transport energy use by 2050 (IPCC, 2007).

The article focuses on primary biomass that comes from plants. Secondly, this article discusses the policy surrounding biomass deployment and freight transport, a subject which has been relatively neglected in the policy reports and assessments on the potential of bio - energy.

Plants use sun rays to convert water and carbon dioxides into sugars by photosynthesis. The study examines how energy use of biomass production and its transport determines the viability of bio energy deployment in the UK. Assessing the transportation options of biomass across the supply chain is key. The article explains biomass feedstock movements within a 50 km radius. Furthermore, the study presents

[2] Sale of alternative fuel vehicles have grown in the OECD region and virtually every major car maker has launched its own flexible fuel car version. However, cars that run on 100% biofuels are still rare. Most cars in the U.S. can run on 10% biofuel, 90% gasoline of total fuel content.

a methodology that allows analysis of impacts of freight biomass flows on emissions and local traffic. For this purpose this study quantifies freight flows for several types of biomass and applies a new methodology to achieve this aim. Results show that careful analysis of transport infrastructure is needed to enhance sustainability, and resilience, of biomass supply chain.

As said above, it is generally claimed that biomass resource use supports carbon mitigation efforts. However, several authors argue that net gain in savings of fossil fuels and of CO_2 are probably less than commonly believed (Searchinger et al. 2008; Delucchi, 2006).

1.1 Background

Since 2000 UK Government policy has provided incentives for the take up of biofuels and for biomass resource use. Witness the renewable energy targets RTFO, in 2007, and the EU energy programmes. The EU renewable energy directive describes the targets on biomass deployment. The EU directive states " an increase in the use of biofuels should be accompanied by a detailed analysis of the environmental, economic, and social impact in order to decide whether it is advisable to increase the proportion of biofuels in relation to conventional fuels." EU Commission, Directive (2003). For this reasons this article aims to examine the environmental and economic impact to guide EU policy on biomass and biofuels deployment.

In the UK, biomass use for power and heat is predicted to grow to 10% of UK electricity production by 2010 following the adoption of the Renewables Obligation in 2000. The analogous target for biofuels is 10% by 2020 for the EU. Currently all renewable energy (including biomass) use accounts for 4.4 % of total fuel use for generating electricity of the UK. The Renewables Transport Fuels Obligation requires a target of 2.5% by volume by 2008 and of 5.75 % by 2010. It remains to be seen if these targets are achieved under a price for oil of only 70 US$ a barrel. It is estimated that profitable biofuels projects require a 40 US$ at a minimum to compete in the motor fuels market. Already current oil price levels are affecting the cost advantage of bioethanol plants over gasoline and diesel.

Transport is a key service for the deployment of biomass feedstock and of biofuels. The academic literature and policy reports lack in depth analysis of biomass supply chain impacts (externaities) on transport. The importance of externalities, resulting from the emergence of new supply chain required for any biomass project, from extra freight transport demand and of new logistics in the policy literature is acknowledged but detailed analysis with quantitative analysis is rarely done. Equally the importance of transport network and mode, infrastructure needs and traffic are rarely looked at in analysis of large scale biomass deployment.

A study by Ademe, cited in by USDA foreign Agricultural Service (2006) asserts that freight transport costs "hardly contributed to the energy balance" for any bioethanol project. This is correlated to the spatial concentration of production facilities. The same USDA source finds higher processing costs for sugar beet to ethanol than wheat to ethanol because sugar beet production is, geographically speaking, spread out much more than wheat, in the EU region, increasing the distance travelled to the refining centres and increasing the distribution costs. This highlights how closely linked the spatial concentration of biomass production (and its refining) and freight flows are. The importance of spatial distribution, and thus of freight transport services, of biomass feedstock should be assessed in any study of biomass market potentials or of the negative externalities of biomass use.

Analysis by the Carbon Trust (2005) identifies several barriers for the successful deployment of biomass, without considering freight transport options.

The Gallagher report (Gallagher, 2008) eloquently identifies the indirect effects on land use change, that results from displaced agricultural production, of biofuels production. The report, however, does not mention freight transport of biomass as representing an essential input for any biomass national deployment programme that requires careful planning if it is to be truly sustainable. The same report focuses on the indirect land use impacts of biofuels production on agricultural land (not biomass per se). The Gallagher review, however, does point out the need to enforce sustainability criteria of biofuels/biomass deployment within the EU Renewable Energy Directive.

A report by the House of Commons (2008) asserts that to accurately measure carbon savings of biofuels it is necessary to account for CO_2 emissions of biomass feedstock or of biofuel transport. However, that report does not examine in detail the possible emissions of CO_2 resulting from biomass feedstock transport and related equipment (for example tractors used in biofuels production and transport). The report asserts "it is clear that biomass for heat and electricity offer greater and more reliable GHG emissions saving than biofuels." This is because the efficiency of biomass (60%-80%) is greater than that of biofuels (30%) .

The Stern review (Stern, 2007) mentions biofuels as a potential technology for CO_2 savings but it does not mention any indirect impact of the biofuel supply as representing significant supply chain barriers.

In contrast to the above reports which underplay freight transport needs in the logistical chain of a biomass infrastructure, the JRC- EU commission (2007) report based on the "Well to Tank" method examines in depth the transport needs (logistic chain and freight moved of biomass) along the supply of chain of each type of biomass. That report argues that the energy and GHG emissions of biomass transportation will be a fraction of the all pathways (entire supply chain of biomass). Again this report ignores externalities of biomass freight transport.

We, however, believe that the energy and GHG emissions as well as the environmental, and other effects, let alone production costs, associated with biomass production are difficult to ignore..

This study introduces a number of innovative features: it combines spatial model with transport activity, (2) it applies empirical data on energy use to estimate overall consumption by mode of transport; (3) it focuses on large scale deployment of biomass infrastructure; (4) and it examines various supply chains of biomass feedstock under different scenarios of power demand. The study combines insights of the effect of the vehicle mix (by class size) and of the biomass mix on the energy delivered.

2. Deriving the demand for freight transport

In this section, we describe how biomass feedstock flows impact on the demand for freight transport. What determines the demand for freight transport? The demand for freight (tonnes lifted times distance travelled, producing: tonne-km, that is, tonnes moved) is a derived demand arising from the need to move a given quantity of primary raw materials which are utilised in electricity and heat generation for processing at a biorefinery or electricity plant, in the case of biomass, within a given region.[3]

To understand freight transport it is necessary to know the physical state of a commodity that the farmer wishes to move. According to Alberici (2004), the biomass feedstock generally shows low bulk densities. Interestingly biomass volume, and not weight, is the limiting factor in their transport (RCEP, 2004). Another determinant of

[3] One issue not explored here is that biofuels that require more land (low yield) may also need more freight transport equipment.

freight transport (in terms of lorry journeys) is the calorific value (energy content) of a tonne of biomass that is moved since biomass energy content is much lower than that of fossil fuels (Allen et al. 1998). The high moisture content of biomass reduces the calorific value even more. The implication of this is that number of (either road or rail) freight transport trips will be greater than that of fossil fuel deliveries. (This is reflected in the results of table 1).

Sims (2004) argues that the interaction among the items listed below influence freight transport flows:

1. Biomass moisture content
2. Dry matter loss
3. Bulk density
4. Delivered energy content
5. Drying rate
6. Storage location and period
7. Distance between resource and plant
8. Truck payload constraints

To the above list one can add :

1. Yields (per hectare) of agricultural land
2. vehicle size
3. warehousing and spatial distribution of the biorefinery (or power plants)

The links among the above are complex but these need to be assessed to deliver biomass cheaply and efficiently. The end result of all biomass supply chain activity is the delivery of the fuel to the power station by freight transport following:

1. Correct quantity
2. Correct quality
3. Schedule
4. Correct costs to meet hourly, daily and seasonal demands of power station operation.

The decisions of the power plant manager shall influence the transport needs of biomass projects as well as transport planning in general (road types, vehicle fleets, etc). In addition to the above, the following are key considerations for transport and logistics:

1. Transport delivery frequency
2. Routing of fuel delivery vehicles
3. Identification of vehicles
4. Access roads
5. Vehicle movements during project’s construction

Other Factors influencing freight transport distance:

- Size of power station and conversion technology
- Crop yield achieved
- Proportion of land around the power stations planted with biomass energy crops (coppice or miscanthus) or crops that have biomass as a bi product (straw) or density of forestry
- Availability of material for biomass resource (straw has competing uses and therefore only a proportion of total output will be available as feedstock).

3. Environmental Impact of freight transport and costs on society

In this section we estimate environmental impact of freight traffic, through the large scale deployment of biomass plants in the UK. Data for biomass feedstock moved (in tonnes lifted). The models provides as outputs: tonnes lifted (tonnes) and tonnes moved (tonne-Km) under different levels of electricity and heat generation.

An examination by type of road is necessary to understand the impact of UK generated biomass on freight transport. The transportation of materials to the plants by lorry can cause some pollution and disruption, although this can be minimised by scheduling freight transport at less disruptive times of day (DfT, 2008).

According to black (1995) the following should be considered when examining the environmental effects of increased vehicle activity (arising from biomass transport):

1. Air quality
2. Cultural heritage
3. Disruption due to construction
4. Ecology and nature conservation
5. Landscape effects
6. Land use
7. Traffic noise and vibration
8. Pedestrians, cyclists, equestrians and community effects
9. Vehicle travellers
10. Water quality and drainage
11. Geology and soils
12. Policies and plans

Methodology

The first step in the study is to:

1. Assess size of road freight vehicles (Heavy Goods vehicles) biomass feedstock;
2. Assess vehicle emission rates for non CO_2 and CO_2 deliveries
3. Assess appropriate biomass mix and energy density and needed energy delivered at the gate;
4. Estimate distance travelled by vehicle for the entire trip.

3.1. **Energy use of freight transport**

A comparison of the level of energy use of the different transport modes (trucks, rail and ships) has been made using a spreadsheet. Below an analysis is presented for freight transport energy use as a function of both transport mode and biomass type. The following biomass types are examined in this study:

Table 1 Biomass Feedstock

Type	Physical Form
Short rotation crop (SRC) (wood chips)	Chips
Short rotation crop (SRC) (wood pellets)	Pellets
Miscanthus bales	Bales
Miscanthus cubes	Cubes
Forestry Residues chips	Chips
Forestry Residues pellets	Pellets

Truck Freight

Figure 1 shows the different levels of energy use (for road freight transport, and by biomass type) needed to move the biomass feedstock. Our calculations show (not shown in figure 1) that the truck mode can “waste” 5 times as much diesel (MJ per tonne moved) compared to the rail mode.

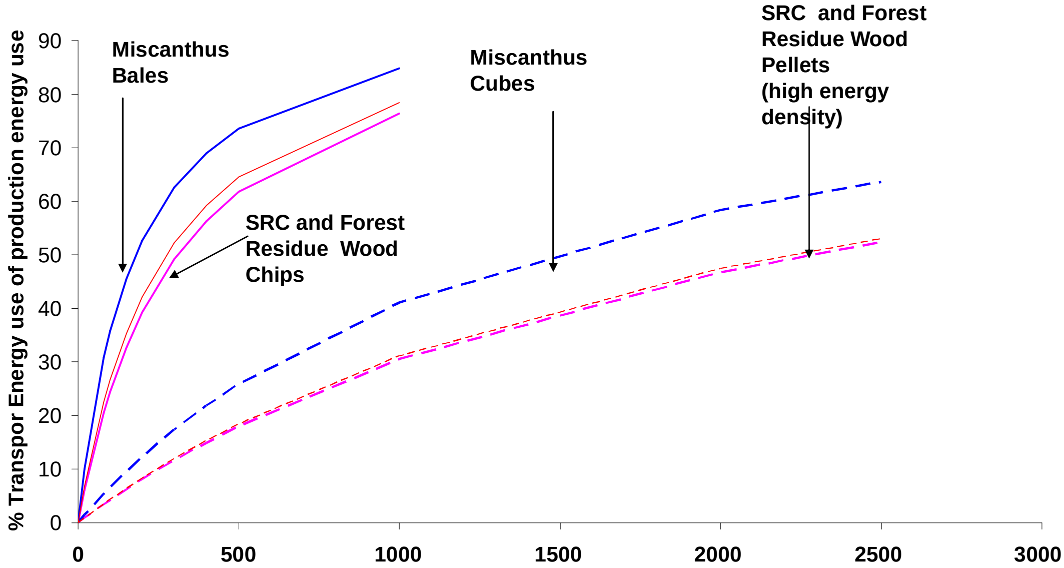


Figure 2. Truck freight energy use (Distance (Km) on the x axis, % energy in the "Y" axis.

Moreover, the fraction of truck energy use to that needed to produce a given amount of biomass, increases exponentially when moving miscanthus bales than SRC (short rotation crops) (Figure 1). SRC and miscanthus cubes can be freighted further distances because of their higher energy density (GJ/tonne) (and thus a larger quantity of energy can be delivered per vehicle trip to the bio-refinery gate) before energy use in transport matches that of energy used to produce a given amount of biomass volume. SRC and wood chips show a rapid increase in the fraction of energy use of trucks as distances increase to 500 km. Miscanthus cubes can be freighted up to 1400 km compared to 500 km for miscanthus bales. This means that it is more energy efficient for biorefiners to freight biomass that has a high energy density.

Failing to do that will mean that high ratio of, and a significant volume of, energy use is needed to transport biomass feedstock relative to the energy use to produce biomass.

Rail freight

Figure 2 depicts how the energy use of rail freight increases less rapidly as a function of distance, for all biomass types. In this case two types of train are considered: diesel and electric; and rates of load are also considered. If the bio energy scheme manager (or farmer) selects rail freight as the mode of transport, within the biomass supply chain, a further saving in energy use (and thus enhancing the sustainability of the biomass supply chain) can be achieved.

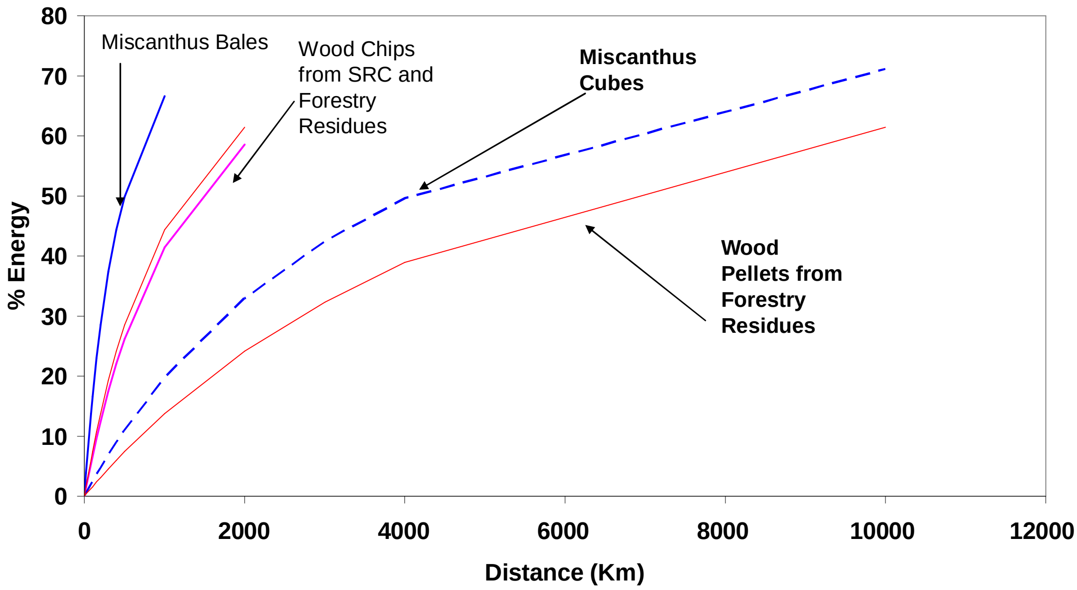


Figure 3. Rail freight of biomass feedstock

However it is uncertain if UK rail freight capacity is sufficient to freight large amounts of biomass feedstock. The data computed shows that the rail mode can save as much as 5 times per tonne moved compared to the road mode.

Railways are capable of magnifying both the market potential of biomass deployment and its utilisation for two reasons. As said already, first railways require less energy per tonne moved in the country. Second the cost of moving one tonne is far lower than the other modes which adds a cost advantage to a biomass scheme. However biofuels will require distribution from the refinery to the point of sale requiring extra freight transport (pipes).

Table 2 depicts our estimates for energy use of biomass transport for the following types of biomass listed in Table 1. Emissions are given by transport mode: trucks, rail and ocean freight. For the sake of consistency, the energy use per tonne-km estimated is checked against data produced in Gilbert and Perl (2008). To compute the figures in Table 2 it is assumed that 1 MW of heat will be generated using this mix of biomass as inputs in the heat plant. If the biomass feedstock was used to generate electricity instead the number of trips would significantly increase. The energy use includes the energy use in production and that of transport for biomass types.

Table 2. Emission per tonne-km moved and energy use

		Current		
Biomass feedstock		**44-tonne Truck**		
		% Load Rate	**MJ/t-km**	**Kg CO2 eq./t-km**
SRC:	Chips	58	**1.63**	**0.11**
	Pellets	100	**1.02**	**0.07**
Miscanthus:	Bales	53	**1.78**	**0.12**
	Cubes	100	**1.02**	**0.07**
Forestry Residues	Chips	58	**1.63**	**0.11**
	Pellets	100	**1.02**	**0.07**
		32-tonne Truck		
		% Load Rate	**MJ/t-km**	**Kg CO2 eq./t-km**
SRC:	Chips	40	**2.80**	**0.20**
	Pellets	100	**1.24**	**0.09**
Miscanthus:	Bales	36	**3.06**	**0.21**
	Cubes	83	**1.45**	**0.10**
Forestry Residues	Chips	40	**2.80**	**0.20**
	Pellets	100	**1.24**	**0.09**

		Diesel Rail Transport		
		% Load Rate	**MJ/t-km**	**Kg CO2 eq./t-km**
SRC:	Chips	100	0.3	0.024
	Pellets	100	0.3	0.024
Miscanthus:	Bales	51	0.6	0.043
	Cubes	100	0.3	0.024
Forestry Residues	Chips	100	0.3	0.024
	Pellets	100	0.3	0.024
		Electric Rail Transport		
		% Load Rate	**MJ/t-km**	**Kg CO2 eq./t-km**
SRC:	Chips	100	0.4	0.019
	Pellets	100	0.4	0.019
Miscanthus:	Bales	51	0.6	0.034
	Cubes	100	0.4	0.019
Forestry Residues	Chips	100	0.4	0.019
	Pellets	100	0.4	0.019
		Marine Vessel		
		% Load Rate	**MJ/t-km**	**Kg CO2 eq./t-km**
SRC:	Chips	40	0.05	0.00
	Pellets	100	0.02	0.00
Miscanthus:	Bales	20	0.10	0.01
	Cubes	84	0.03	0.00
Forestry Residues	Chips	40	0.05	0.00
	Pellets	100	0.02	0.00
These figures are based on a hypothetical demand for heat of 1 Megawat with 80% plant efficiency. The figures also take into account the energy density of the biomass moved.				
SRC: short rotation crop; MJ: megajoules; t-km: tonne times km driven by a mode of transport;				
Source: C. Whittaker (Imperial College, Biology Department)				

Ocean Freight

By far the most efficient mode for moving freight is the maritime freight mode (Table 1). On average, this mode requires only (0.05 MJ/tonne-Km divided 1.63 MJ/Tonne-km) less than 5% road freight to move one tonne, of biomass cargo, by one kilometre. The calculations also account for different vessel load rates.

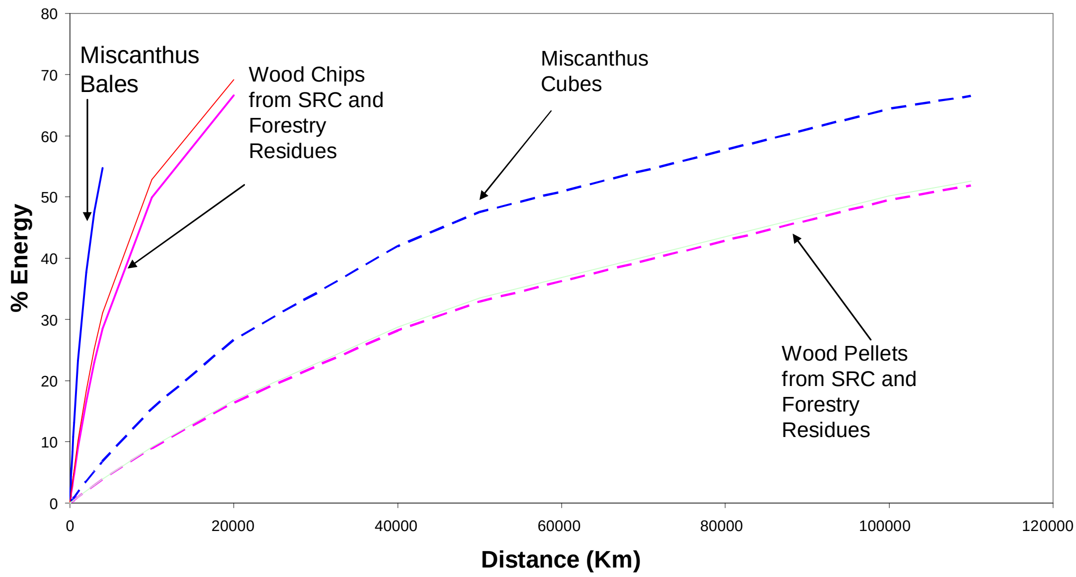


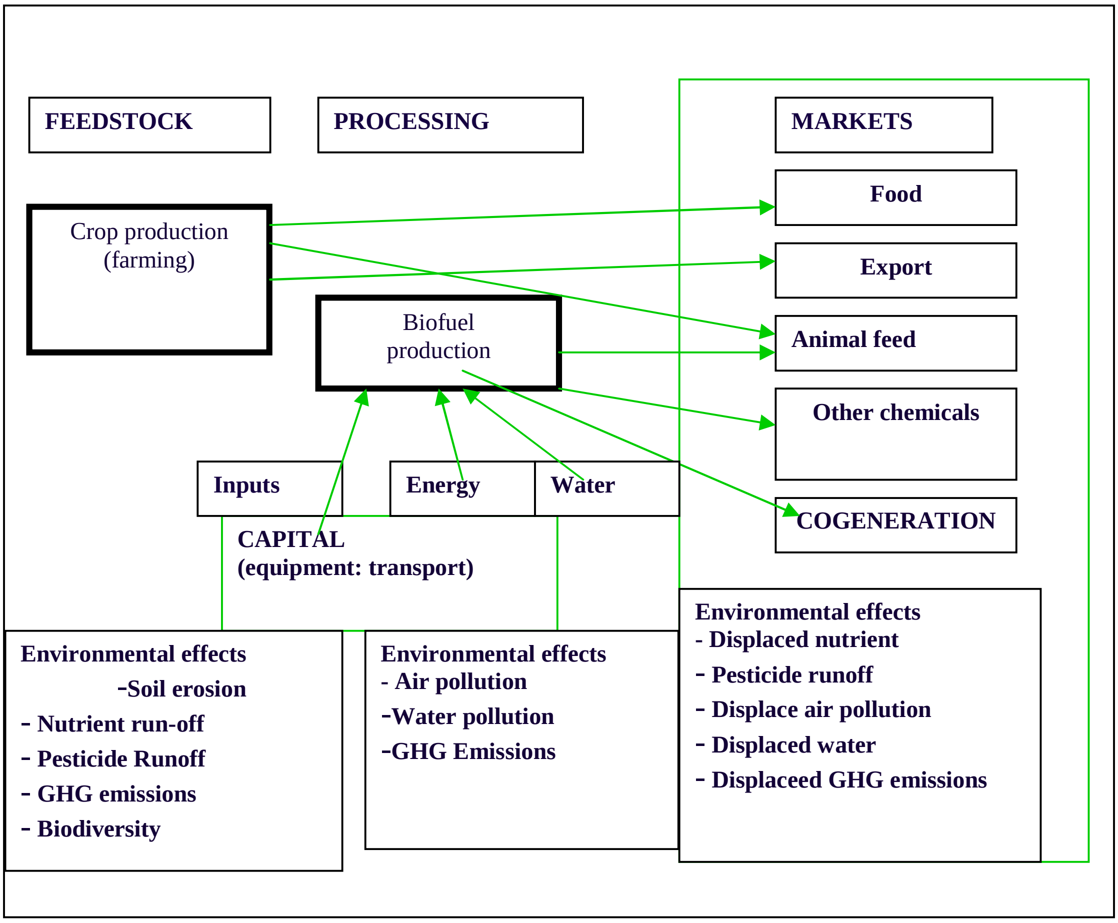
Figure 4. Ocean freight energy use of biomass feedstock

If, and only if, the ocean freight option is selected by the bio energy investor (farmer), this mode of transport is not free from deleterious impacts on the environment. If the volume of biomass imported to the UK is large this could increase the port congestion, sulphur and nitrogen oxide emissions in populated areas or regions. Moreover, opting for this option would require port investments in infrastructure and storage for handling biomass feedstock some of which requires special care.

4. Energy efficiency and environmental effects of biomass supply chain

What is the energy use of trucks vs. rail per tonne moved in the supply chain? A clear understanding of the biomass supply chain is needed to understand the indirect transport impacts of biomass use. The figure below (based on Kammen et al. (2008) shows the steps that need to be examined. Moving from left to right, and from one block to another, requires freight transport including vehicles, tractors and storage. Producing biomass feedstock (crop growing and its production) at the farm requires transport equipment and logistics. Transport is also needed to bring the biomass to the processing center (power plant, biorefinery). The final stage shown in the large rectangle (shown on the right of the diagram) also needs energy use for transport, as biofuel produced will have to be distributed to the fuel service stations across the country. If the biomass is utilised in power and heat generation transportation mode of choice will be the pipeline or a heat network close to the factory.

1. Biomass supply chain



Limitations

Our findings show that further examination of fuel consumption along the biomass supply chain is needed for:

1. Fuel consumed in mechanically harvesting, processing, handling and transporting the fuels from farm and forests to power station
2. harvesting activity
3. loading and unloading and handling
4. Environmental impacts of freight transport movements (vehicle pollutant emissions,
5. vehicle noise and the addition to existing traffic levels that a biomass scheme will result in and hence the increased potential for road traffic accidents.

International distance, for biomass imports, travelled should be accurately calculated to fully capture the entire GHG emissions and fossil fuels consumption

Conclusions

Designing an energy policy based on biomass brings new challenges since biomass logistics may itself be freight transport intensive. At current trends the demand for motor fuel and electricity will increase pressure on world fossil fuel supply and increase GHG emissions. This requires urgent solutions. One solution is to increase the diffusion of flexible fuel trucks and cars which in turns needs a larger supply of biofuels. In the UK, biomass use for power and heat is predicted to grow following the adoption of the Renewables Obligation in 2000 which brings implications for freight transport. The analogous target for biofuels is 10% by 2020 for the EU. It is generally believed that biofuels and bio energy deployment mitigates carbon emissions and saves fossil fuels.

- However, we find that extensive utilisation of biomass may increase transportation needs and distances travelled. The increase in the number of vehicle trips to deliver biomass feedstock was estimated as well as its related energy use.

- Energy use of biomass transport will vary from long distances for rail to short distances for trucks; it will also vary with the type of biomass moved to the power station because the energy density of biomass will vary. Trucks will require more energy per tonne moved if compared to railways.
- Railways are capable of magnifiying the market and technology potential of biomass deployment and its utilisation as railways require less energy required per tonne moved in the country.
- Successful biomass delivery to plants will need railway capacity expansion requiring new infrastructure investment.
- Most biomass schemes will be 50 km distance from the cropping fields or supply sources but the demand for transport services has the potential to increase (1) diesel consumption, (2) CO_2 emissions, (2) non- CO_2 emissions, (3) accidents, (4) environmental costs (5) and social costs of UK generated biomass schemes.
- Less CO_2 intensive transport modes magnify the market potential of biomass use since energy use of ocean freight and trains is significantly less to that of trucks. Specific features of biomass feedstock transport and its logistical chain are identified. Different supply chain options of biomass are also discussed through selected case studies.
- Future work should estimate life cycle energy and GHG balance as well as the monetary impacts of emissions of the extra freight transport. Studies should consider the international and local dimension.

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