Presented at: 4th Biomass Conference of the America's, August 29-September 2, 1999, Oakland, CA, USA

Energy Crops versus Waste Paper:
A System Comparison of Paper Recycling and Paper Incineration on the basis of Equal Land-Use

Marko Hekkert, Richard van den Broek, Andre Faaij

Utrecht University, Department of Science, Technology and Society, Padualaan 14, 3584 CH Utrecht, The Netherlands, email: M.P.Hekkert@chem.uu.nl

Due to the renewable nature and CO_2 neutrality of biomass, one may expect a large future demand for both biomass energy and biomass based materials. Because land availability is limited, at some point choices need to be made about the type of biomass that is grown and for which purposes it is used. In this paper we compare the related CO_2 emissions of two biomass based product cycles. In the first system biomass is used for the production of paper which is directly used for energy recovery after consumption. In the second system paper is largely produced from recycled fibers. The land area that becomes available by paper recycling is then used for energy crop production. Preliminary results show that the second system leads to lower energy use and reduced CO_2 emissions.

1. INTRODUCTION

There is a growing interest for both biomass based energy and materials, due to the renewable nature and CO_2 neutrality of biomass. Current research in for example biofuels, biomass gasification and bioplastics subscribe this interest. Also in current material use shifts are visible from oil based products to biomass based products, like substitution of plastic shopping bags by paper bags in many countries.

Because land is a limited resource, at some point in the future choices may have to be made about the use of land for biomass production for various purposes. These choices are complex because insight in the whole production and consumption chain is needed in order to be able to judge the influences of choices made. An example of possible choices is the choice between short rotation biomass for energy production or long rotation biomass for material production.

Besides the type of biomass used, in many stages in the product life cycle choices need to be made about the use these biomass based products. One of the major questions related to these choices is whether to recycle biomass based materials or to use them directly for energy recovery? The relevance of this question is revealed by the large number of studies that are dedicated to this subject. Most studies focus on the matter of paper recycling versus energy recovery from waste paper (1,2,3,4). Comparison of the results of these studies does not give an unambiguous answer about whether paper recycling is environmentally advantageous over paper incineration. Causes for these differences involve the assumptions made and differences in system boundaries (5).

Up till now it is not common to explicitly integrate land use considerations with the analysis of environmental impacts of material use. A reason for this may be that Life Cycle Assessments, which are suitable to compare environmental impacts of different life cycles, use separate impact categories for land use and other environmental effects. It is not common to integrate these impact categories.

In this paper we try to integrate land use and environmental impacts of biomass based materials by using a broader system comparison. When all environmental impacts are taken into account such a system comparison is basically an LCA with expanded system boundaries. For this paper we just focus on land use and climate change in order to keep the comparison comprehensible. Furthermore, we use newsprint as a biomass based material case. Such a system comparison should lead to preliminary insights in whether biomass production should be focused on material or energy production and whether newsprint should be recycled or used for energy recovery.

In this paper we compare two systems. In the first system biomass is used for the production of paper which in turn is directly used for energy recovery after consumption. In the second system newsprint is largely produced from recycled fibers. The land area that becomes available through this paper recycling is now used for energy crop production. We compare the two systems on energy use and CO_2 emissions.

2. SYSTEM DESCRIPTION

The system comparison is based on current practices in The Netherlands. The newsprint is assumed to be produced and consumed in this country. Because the forest industry in The Netherlands is small, wood pulp is imported from other countries like Sweden. In Figure 1 the two systems that are compared in this paper are depicted. In Table 1 basic input data for the analysis are presented. In this analysis the production of 1000 tons of newsprint is used as functional unit.

System A is a representation of the situation where no waste paper is recycled. Newsprint is produced and collected with other municipal solid waste after being used. It is disposed in a waste incineration facility with energy recovery. The pulp used for newsprint production is mechanical pulp and is imported from Sweden. Mechanical pulping is an electricity intensive process.

In order to avoid an even more extended system analysis in this preliminary study we assumed hybrid poplar plantations for fiber production because current harvest practices in Central Europe result for example for pine in 45% sawlogs, 34% pulpwood, 8% fuelwood and 8% waste (8). This multi product output makes is difficult to allocate the reduced demand for pulpwood to land use. For hybrid poplar the relation between land use and demand for pulpwood is straight forward because poplar is solely used for pulpwood production. For poplar production in Sweden we assumed a rotation period of 15 years. In system A, transport of wood and pulp by truck is needed in Sweden, transport of pulp by boat is needed to The Netherlands and within The Netherlands both transport of pulp and waste paper by truck is necessary.

Figure 1. Schematic overview of system comparison (the dashed lines represent energy flows and the solid lines represent product flows)

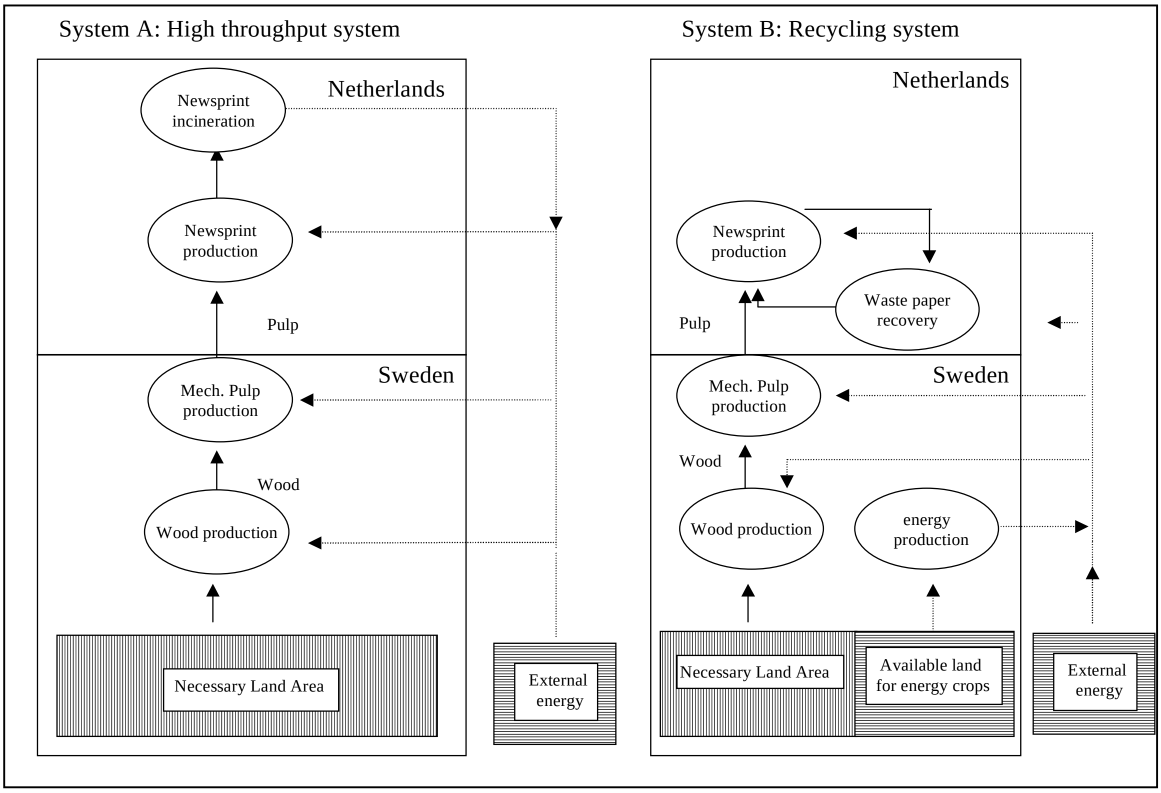

Table 1

Description of input data

	unit	value system A+B	Value System A	Value system B	source
Energy use truck	MJ/ton/km	2.9			(10)
Energy use boat	MJ/ton/km	0.23			(10)
International transport	km	1000			(14)
Transport in The Netherlands	km	100			
Transport in Sweden	km	80			(14)
CO_2 emissions electricity prod. Sweden	kg/GJ_{el}	15			(12)
CO_2 emission elec. prod. The Netherlands	kg/GJ_{el}	158			(12)
CO_2 em. fuel mix district heating Sweden	kg/GJprim	53			(13)
Yield hybrid poplar production	t.d.m./ha/yr	4.7			(9)
Yield willow production	t.d.m./ha/yr			9.3	(10)
Energy use willow production	GJ_{prim}/ha/yr			6.9	(10)
Energy use poplar production	GJ_{prim}/ha/yr			2.6	(14)
Energy use mechanical pulping	GJ_{el}/ADMT	8			(7)
Electricity use waste paper recovery	GJ_{el}/ADMT			2.2	(11)
Heat use waste paper recovery	GJ_{th}/ADMT			1	(11)
Electricity use newsprint production	GJel/ADMT	1.5			(6)
Heat use newsprint production	GJ_{th}/ADMT	2.3			(6)
Electric efficiency waste incinerator	%		24		

System B represents the situation where a maximum amount of newsprint is collected and recycled after use. The recycling process is assumed to be a flotation deinking facility and is located in The Netherlands. Less wood pulp is imported from Sweden which results in reduced land use. The available land is used for short rotation willow production. The willow chips are used as fuel for district heating in Sweden. By doing so, it replaces a mixture of energy carriers, i.e., wood fuels, peat, oil, blast furnace gases and electricity for heat pumps and boilers. For (international) transport we used the same figures as in system A.

For both systems external energy is needed. The type of energy used and the related CO_2 emissions is largely influenced by the country where the processes are located. In The Netherlands a large part of the energy supply is fulfilled by natural gas while this energy source is hardly used in Sweden. Furthermore, the CO_2 emissions related to electricity production are much lower in Sweden than in The Netherlands due to the large input of nuclear and hydro-energy in Sweden and the large input of coal and natural gas in The Netherlands.

3. RESULTS

In Table 2 the material use, energy use and CO_2 emissions of both systems are presented. Moreover, Table 2 shows the division of land use. It shows that in system B more wood on the same acreage is produced than in system A. This is the result of the higher productivity of willow for energy purposes compared to poplar for fiber purposes. Table 2 also shows that system B uses much less energy than system A; in system B even more energy is produced than consumed. The large difference in energy use is also reflected in the difference in CO_2 emission.

4. DISCUSSION

The results of the system comparison are influenced by a number of assumptions and system choices. Three aspects are important in this matter: selection of technologies, selection of countries and determination of reference energy sources.

The selection of technologies is important, the efficiency of the processes as well as fuel input. In this paper we have chosen paper incineration in a municipal solid waste incinerator and combustion of willow for district heating. Other possibilities are conversion of waste paper and biomass to electricity using incineration in biomass incinerators, co-firing in pulverized coal boilers and biomass with combined cycle.

Besides choices for conversion technologies also choices for pulp processes will greatly affect the results. In this paper we have analyzed the situation for newsprint using mechanical pulp. For chemical pulp that uses lignin for energy production the outcome may differ.

The effect of the country specific data on the system comparison is shown in Table 2 by the large consumption of CO_2 extensive electricity in Sweden. The differences in carbon intensity of electricity between Sweden and The Netherlands not only influences the CO_2 emissions of processes located in Sweden or The Netherlands but also the avoided CO_2 emissions when electricity is produced.

Table 2

Land use, material use, energy consumption and CO_2 emissions of the two systems compared in this paper for a fixed surface of land and 1000 tons of paper.

	Process	quantity (ADMT)	energy use (TJ_{prim})[1]	CO_2 emissions (tonnes)[1]	land use (ha.yr)
System A	Paper making	1000	6.3	338	
	Pulp making	1100	21.8	128	
	Poplar production	1198	0.6	45	231
	Transport		0.6	49	
	Paper incineration		-10.9	-691	
	Total of processes		**18.4**	**-131**	
	Total land use				**231**
System B	Paper making	1000	6.3	338	
	Pulp making	267	5.3	31	
	Deinked pulp making	833	5.5	326	
	Poplar production	290	0.7	51	56
	Willow production	1788	1.2	90	175
	Transport		0.3	21	
	Biomass incineration		-29.6	-1534	
	Deinking sludge incineration		-2.2	-140	
	Total of processes		**-5.1**	**-816**	
	Total land use				**231**

[1] negative figures represent energy production or avoided CO_2 emissions.

CO_2 emissions are avoided when electricity or primary energy sources are produced that replace fossil fuels or fossil fuel based electricity. For the analysis in this paper we have assumed that biomass production in Sweden would be used for district heating since biomass is already used intensively for this purpose (13). The question remains: what type of fuel is replaced when extra biomass is used for district heating? In this analysis we assumed that the biomass produced in system B replaces the mixture of energy carriers that is now used for district heating in Sweden. The choice for alternative energy sources has great influences of the outcome of this system analysis. When we would have chosen that the produced biomass would be converted into electricity to replace Swedish electricity, the total CO_2 emissions of system B would amount to +587 tons. In this case system A should be preferred over system B from a CO_2 emission point of view. The choice of alternative energy sources is also greatly dependent on country specific conditions. However, when the entire production system is located within one country differences in CO_2 intensity of electricity would not exist and the replaced primary energy sources would be equal in both systems. In that case the difference in CO_2 emissions between system A and B would be from the same order of magnitude as the difference in energy use. Recycling is then preferred from a CO_2 point of view when the created land space is used for energy purposes.

5. CONCLUSIONS

Under the standard assumptions made in this paper, maximum recycling of newsprint has smaller CO_2 emissions and less energy use than direct incineration of waste paper. However, other definition of the reference system may turn the results regarding CO_2 emissions around. From an energy point of view it is always best to close the paper cycle as much as possible and use the created land space for energy crops.

Including land use in system comparisons of different product life cycles is useful. It can lead to insights in how to combine both land and material flow management.

This study was a preliminary approach in which land use was explicitly integrated in an environmental system comparison. Follow-up work will elaborate on the sensitivity of the regional and technological choices made and on the methodological questions regarding the choice of reference energy systems.

REFERENCES

1. Virtanen, Y, S. Nilsson (1993). Environmental Impacts of waste Paper Recycling, International Institute for Applied Systems Analysis, Earthscan Publ. Ltd., London, U.K.
2. British Newsprint Manufacturers Association (1995). Recycle or Incinerate? The Future for Used Newspapers: an Independent Evaluation, U.K.
3. Byström and Lönnstedt (1995). Waste Paper Recycling: Economic and Environmental Inpacts, Proceedings, LCA - A challenge for Forestry and Forest Industry, Hamburg (D)
4. Kärnä et al. (1994). Life Cycle Analysis of Newsprint: European scenarios, Paperi ja Puu (4), 76, pp. 232-237.
5. Teeuwisse, S. (1998) A Comparison of Life Cycle Analyses about Paper and Board Products, Depart. of Science, Techn. and Society, Utrecht University, The Netherlands.
6. Nilsson, L.J. et al. (1995). Energy Efficiency in the Pulp and Paper Industry, American Council for an Energy Efficient Economy, Washington DC, USA.
7. Komppa, A. (1993). Paper and Energy: A Finnish view, Proceedings, Int. Conference on Energy Efficiency in Process Technology, Commission of the European Communities, Brussels, Belgium.
8. Muiste, P. (1997) Actual Forestry Market in Estonia, Import of Biomass, Workshop document of a study trip to Estonia and Sweden, Biomass Technology Group, Enschede, The Netherlands
9. Christie, J.M. (1994). Provisional Yield Tables for Poplar in Britain, Forstry Commission technical Paper 6, Forestry Commission, Edinburgh, U.K.
10. Börjesson, P.I.I. (1996). Energy analysis of biomass production and transportation, Biomass and Bioenergy Vol. 11, No. 4. pp. 305 - 318
11. McKinney, R.W.J. (1995) Technology of Paper Recycling, Glasgow, U.K.
12. OECD (1997) Energy Balances of OECD countries, 1994-1995.
13. Nutek (1997) Energy in Sweden 1997, Stockholm, Sweden
14. Agterberg, A. E, A.P.C. Faaij (1998) Bio-Energy Trade, Possibilities and constraints on short and longer term, Department of Science, Technology and Society, Utrecht University, The Netherlands