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D25: Life cycle energy balances on a number of crop species

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PP	Restricted to other programme participants (including the Commission	
RE	Restricted to a group specified by the consortium (including the	
CO	Confidential, only for members of the consortium (including the Commission Services)	

D25: Life cycle energy balances on a number of crop species

The energy efficiency of any biomass based energy system is dependent on the energy requirement of the biomass used as well as the energy requirements of the energy production process. In order to determine these energy requirements an analysis of the life cycle of the crop growth is required. The energy requirements can be identified as being of two types:

- direct
- indirect.

Direct energy requirements are those which directly involve the use of fuel in the operation, for example diesel used in tractors and lorries. Indirect energy is the energy consumed in the construction and delivery of products used in the crop production, these may include fertilisers, sprays, seed etc. Indirect energy is also considered in terms of energy required to construct and maintain equipment used. These are indicated in Figure 1.

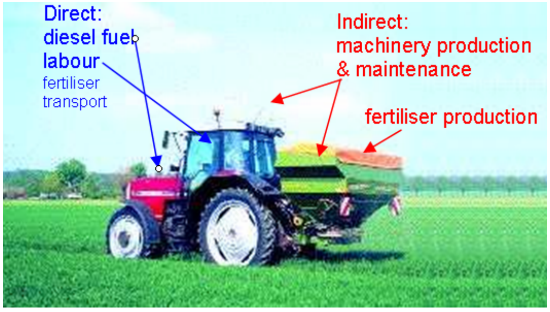

Figure 1: Direct and indirect energy requirements

As with all life cycle analyses the boundaries need to be established, these are shown in Figure 2.

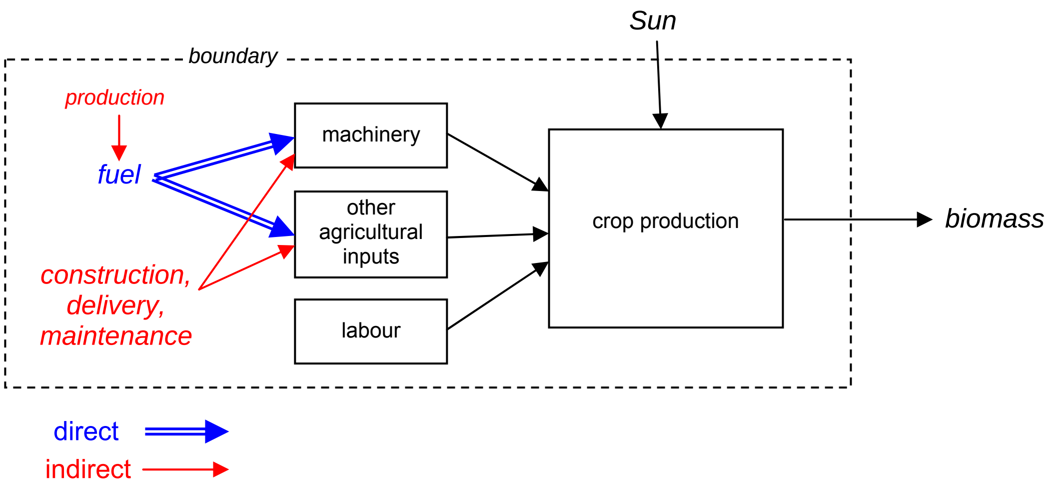

Figure 2: life cycle boundaries for crop production

In keeping with other life cycle analyses conducted, energy from the sun is considered outside the system boundary. This makes it possible then to directly compare the results here with those of other studies.

The basic components of a crop production system are similar for all crops:

1. ground preparation
2. sowing
3. crop maintenance
4. harvest (possibly including destruction of post harvest residues).

The number and type of operation conducted within each of these components will vary according to the crop.
Ground preparation involves the use of tractors and equipment such as ploughs, subsoilers, harrows etc. Sowing requires tractors, drills and seed. Crop maintenance requires tractors, sprayers, fertiliser spreaders, sprays and fertiliser. Harvest will involve harvesters, tractors, trailers and possibly some drying facilities. All of these operations require direct input in the form of fuel and labour plus indirect energy requirements for each piece of equipment.
Fuel consumption can be calculated from figures given in the literature (Bowers, 1993, Dalgaard et al., 2001, Hülsbergen and Kalk, 2001, KTBL, 2002, Leach, 1976, Richards, 2000, Tzilivakis et al., 2005) and from recordings of farmers and contractors. Indirect energy requirements are calculated based on energy requirements for production (including material extraction), delivery, maintenance and repair of equipment. This value is then divided by the average life expectancy of the equipment and the number of hectares in which is used annually. Values here are taken from the literature, particularly Leach (1976) and Bowers (1993). A detailed example of energy requirements for ploughing is shown in Table 1. The amount of fuel consumed is dependent on soil type, ground conditions and equipment used. (Diesel fuel is assumed to have a net caloric value of 35.8 MJ/l + 10% indirect energy giving a total of 40.3 MJ/l). A range of values and average value for operations used in the following energy balances is shown in Table 2.

Table 1: Direct and indirect energy requirements for ploughing

equipment	size	indirect energy	reference
tractor	90kW	564 MJ/ha	a,b
plough	5 furrow reversible	120 MJ/ha	a,b
		direct energy	
fuel used	low rate	13 l/ha	c
	av	17.5 l/ha	
	high rate	23 l/ha	d

References: a: (Leach, 1976), b: (Bowers, 1993), c: (Cropgen **D18**), d: (KTBL, 2002)

Table 2: Example energy requirements for various crop operations

Operation	Energy requirement (MJ ha^{-1})	Average energy requirement (MJ ha^{-1})	Reference
ploughing	624-1160	800	a,b,c,d,e,f,g
seedbed cultivations	138-278	160	a,b,d,f,g
fertiliser applications	59-88	81	a,b,d,e,f
combine harvesting	568-617	598	a,b,c,d,f

References: a: (Leach, 1976), b: (Richards, 2000), c: (Bowers, 1993), d: (Dalgaard et al., 2001), e: (Hülsbergen and Kalk, 2001), f: (KTBL, 2002), g: (Tzilivakis et al., 2005)

Estimates of the energy requirements the manufacture of fertilisers and pesticides, and estimates of this have also been variously made and reported (Jenssen and Kongshaug, 2003, Kongshaug, 1998, Mortimer et al., 2004, Tzilivakis et al., 2005). Average values are shown in Table 3.

Table 3: Energy requirement in fertiliser and pesticide production

	Energy requirement
NH_4NO_3	40.6 MJ kg^{-1}
P_2O_5	15.8 MJ kg^{-1}
K_2O	9.3 MJ kg^{-1}
herbicides	264 MJ kg^{-1} a.i. *(active ingredient)*
fungicides	168 MJ kg^{-1} a.i.
insecticides	214 MJ kg^{-1} a.i.

A detailed example of the operations, including equipment used, time and fuel requirements for a commonly used energy crop for biogas production - forage maize - is shown in

Table 4.

Table 4: Energy requirement in the production of a forage maize crop

operation	Number of operations	equipment	time (h/ha)	indirect energy of equipment (MJ/ha)	tractor (kW)	fuel used (l/ha)
subsoil	1	subsoiler	1.333	120	90	14.6
plough	1	plough + press	1.333	120	90	17.5
drill/harrow	1	combined drill and harrow	0.62	158	90	3.9
fertiliser	1	fertiliser spreader	0.36	45	55	1.2
spray	2	sprayer	0.54	68	55	2.4
harvest	1	forage harvester	2	420		17.5
cart	1	trailer	2	120	55	7.8
ensile	1	tractor and bucket	1.48	8	55	5.8
tractor		90 kW	3.286	564		
tractor		55 kW	4.38	297		
fuel				2785	MJ/ha	70.7
total indirect				1920	MJ/ha	
labour		hours *1.94 MJ/hr (Leach, 1976)*	9.7	18.8	MJ/ha	
seed		kg/ha	16	215	MJ/ha	
chemicals			(kg/ha)			
N			150	6045	MJ/ha	
P_2O_5			200	680	MJ/ha	
K_2O			175	1277.5	MJ/ha	
packaging & transport				1362	MJ/ha	
sprays			12.8	2432	MJ/ha	
total energy input to crop production and storage				**16.7**	**GJ/ha**	

The nature of the crop being grown also has an affect on energy requirement. Winter sown varieties tend to have higher energy requirements than spring sown as they require extra operations in the period before the winter and usually extra sprays and fertiliser applications. The winter sown varieties tend to have higher yields due to the longer growing season. Whether a crop is annual or perennial also affects the energy requirement. Annual crops (for example, wheat, rice and maize) are sown in one year and harvested within the same 12 month period, thus requiring the full set of operations each year. Perennial crops (for example grass, clover and Lucerne) are sown in one year but may then be harvested over a number of years. This reduces the requirement for ploughing and other forms of land preparation, however, these crops usually require more than one harvest per year).

Differences appear when the values derived from the literature are compared with those recorded by farmers as shown in Table 5. This will occur as a result of different land and operating conditions, the literature values being averages or recorded under a specific set of conditions. For example, the fuel consumption according to KTBL (2002) data is consistently lower than that according to information provided by farmers, whereas differences in working time are within a normal range, depending on deviations in field sizes, mechanization and transport distances. Literature values must therefore be taken only as indicators of performance and not as actual values – these will depend on specific circumstances.

Table 5: Working time and fuel consumption for 4 different substrates used for a biogas plant once related to [ha] and once to [t DM]. Data according to the information by the farmers and to the literature (KTBL).

Crop	Working time [h/ha] farmers	Fuel consumption [l/ha] farmers	Working time [h/ha] KTBL	Fuel consumption [l/ha] KTBL
Silo maize	10.1	127	10.0	101
Clover grass (3 cuts)	13.3	90	11.7	80
Sunflower	10.0	93	12.1	82
Bean mix*	5.2	99	6.8	78

Crop	Working time [h/t DM] farmers	Fuel consumption [l/t DM] farmers	Working time [h/t DM] KTBL	Fuel consumption [l/t DM] KTBL
Silo maize	0.70	8.9	0.70	7.1
Clover grass (3 cuts)	1.32	9.0	1.16	8.0
Sunflower	0.97	9.0	1.18	8.0
Bean mix*	1.57	30.0	2.06	23.6

* mix of bean, barley, oat, pea, rape, mustard

Determining the correct units of measurement is important when evaluating the energy requirements for crop production. As shown in Table 5, the order of energy requirement per tonne of dry matter can be very different to that of energy per hectare. These differences are further indicated in Figure 3 and Figure 4.The differences in crop yields per hectare can be seen to have considerable effect in terms of energy requirement. For example barley (whole plant silage) and grass silage (harvested with mower and trailer) needed the lowest input on working time and fuel, while potatoes and forage beet needed the highest input. Referring to the units [h/t DM] and [l/t DM] barley, wheat and maize as whole plant silage, and forage beet needed the lowest input and potato, wheat grains, rye and grass silage (harvested with a chopper) needed the highest input.

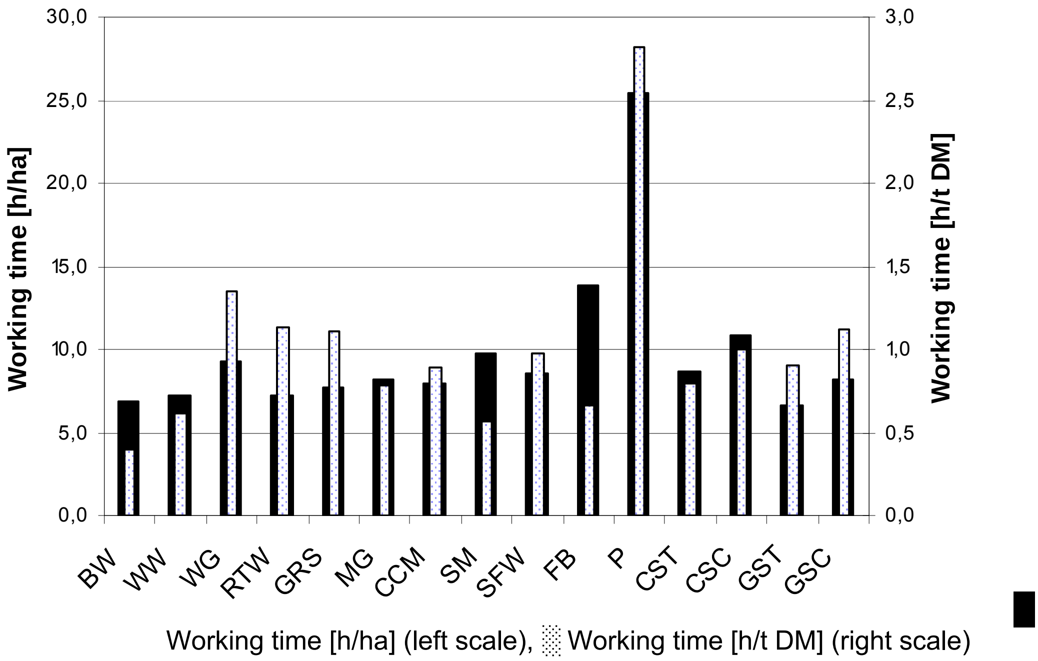

Figure 3: Comparing the working time needed for 13 different crops using a plough for the cultivation.

BW Barley WPS; **WW** Wheat WPS; **WG** Wheat grains; **RTW** Rye and triticale WPS; **GRS** Green rye as silage; **MG** Maize grains; **CCM** Corn-cob-mix; **SM** Silo maize; **SFW** Sunflower WPS; **FB** Forage beet; **P** Potato; **CST** Clover grass silage (trailer); **CSC** Clover grass silage (chopper); **GST** Grass silage (trailer); **GSC** Grass silage (chopper)

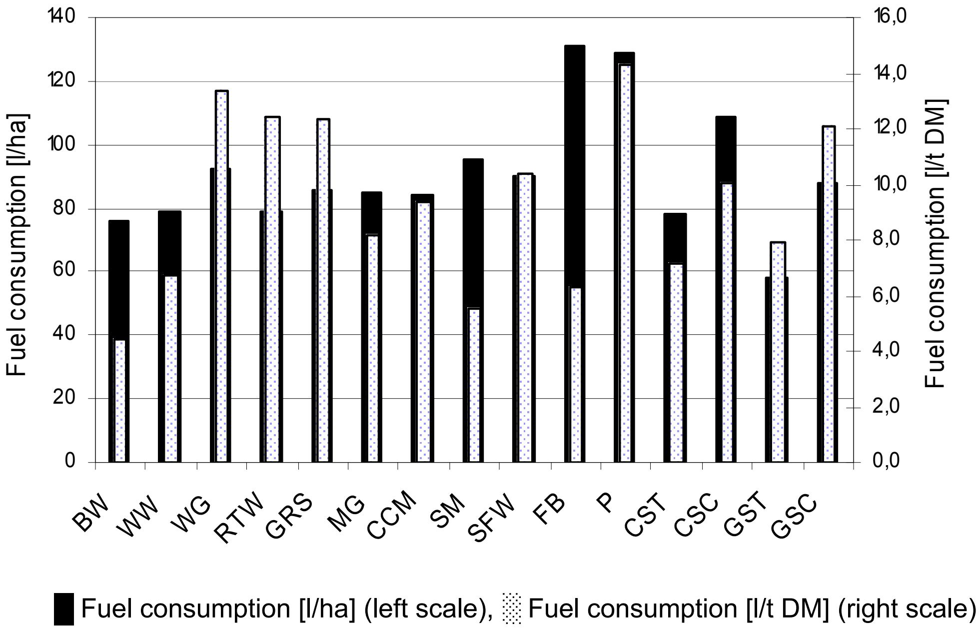

Figure 4: Comparing the fuel needed for 13 different crops using a plough for the cultivation.

Additional savings in working time and fuel consumption can be achieved by using alternative cultivation methods: Cultivation by direct sowing instead of using a plough or a grubber can save working time from about 10% (clover grass silage) to 41% (winter barley WPS) and fuel consumption from about 11% (clover grass silage-chopper) to 42% (winter barley WPS) by direct sowing, respectively.

A simplified method for calculating fuel requirements can be made through knowledge of the working width of equipment used, travel speed and fuel consumption for the relevant tractor used. An example of this method for growing a crop of timothy grass in Finland is shown below. Timothy grass is a perennial crop which can be sown and then harvested over a period of four years. Table 6 presents values of workwidth, tractor speed and times for each procedure of cultivation and harvesting of timothy grass for calculation of the consumed labour time of certain field area. Average fuel consumption of tractor is 18 l h^{-1} (tractor manufacturer Valtra).

Table 6: Values for calculation the labour time for cultivation and harvesting of timothy grass.

	Workwidth [m]	Speed [km·h^{-1}]	Procedure carried per year
Ploughing	2	7	0.25
Liquid fertilisation	15	8	2
Solid fertilisation	6	8	0.25
Harrowing	4.5	7	0.25
Seedbed cultivation	4	7	0.5
Rolling	4.5	7	0.5
Sowing and fertilisation	3	6	0.25
Moving	3.2	7	2
Harvest	6.4	7	2
Liming	12	7	0.25
Spraying	20	8	0.5

Note : where the procedure carried out per year value is less than 1 indicates that the procedure has to be carried less frequently than annually.

Table 7 presents the energy balances for a number of annual crops. These are 'average' values assuming all crops are grown under the same field conditions are fertilised at the recommended rate using mineral based fertilisers and pesticides, having the energy requirements given in Table 3. (The reference table for operations is shown in Table 8.

Table 7: Energy balances for annual crops

crop	sowing period	operations per year	energy requirement (GJ/ha) indirect	fuel (l/ha)	fertiliser & sprays	total	yield (tFM/ha)
maize	spring	a,b,e,g,2h,j,k,l	1.92	2.78 (71)	11.8	**16.7**	40
wheat	winter	b,e,f,g,2h,j,k,l	1.84	2.26 (57)	12.7	**17.0**	36.5
fodder beet	spring	b,2c,g,d,2h,j,k,l,m,k	3.76	3.38 (86)	14.4	**21.8**	80
triticale	winter	b,e,f,g,2h,j,k,l	1.84	2.26 (57)	11.6	**16.0**	38
sunflower	spring	b,e,f,2g,h,j,k,l	1.85	2.26 (57)	10.9	**15.3**	35 (est)

lupin	spring	b,e,f,g,h,j,k,l	1.81	2.20 (56)	4.3	**8.6**	30 (est)
field bean	winter	d,g,b,2h,j,k,l	1.64	2.05 (52)	3.83	**7.8**	35 (est)

note: for crops not currently grown for biomass, yields are estimates

Table 8: Operations reference

a	subsoil	e	drill/harrow	i	combine harvester	m	root harvester
b	plough	f	roll	j	forage harvester	n	mower
c	seedbed cultivations	g	fertiliser application	k	cart	o	turner
d	drill	h	pesticide application	l	ensile		

For perennial crops the analysis is conducted in two parts:

1. year of sowing
2. following years

The sum of the energy required over the lifetime of the crop can then be calculated and averaged for each year. Energy balances for perennial crops are shown in Table 9.

Table 9: Energy balances for perennial crops

crop	year	operations per year	energy requirement (GJ/ha) indirect	fuel (l/ha)	fertiliser & sprays	total	yield (tFM/ha)
perennial ryegrass	1	b,2c,d,f,g,h,n,o,j,k,l	2.4	2.62 (67)	12.1	**17.7**	33
	2,3	3g, h, 3n,3o, 3k,3k,3l	4.2	4.62 (117)	12.1	**21.1**	42
Timothy grass	1	b,2c,e,2f,2g,2o,2j,2k,2l	2.3	4.2 (105)	13.5	**20.4**	37
	2,3,4	2g,2o,2j,2k,2l	1.4	2.1 (54)	13.5	**17.0**	36
Clover	1	b,2c,d,f,g,h,n,o,j,k,	2.1	2.37 (60)	7.3	**12.3**	42
	2	2g,1h,2j,2k,2l	2.3	2.59 (66)	7.3	**12.2**	40
Lucerne	1	b,2c,d,f,g,h,n,o,j,k,	2.1	2.37 (60)	6.4	**11.5**	42
	2+	3g,3h,3j,3k,3l	3.7	3.9 (100)	6.4	**14.1**	45

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