Energy balance – Germany 2001: supplementary energy trade balance

The official German energy balance[1] includes energy flows for fuels (e.g. domestic biogas production or oil imports). The crude oil import is counted totally independent of the purpose (producing energy or material). Material produced from oil or gas is officially called 'non-fuel application energy (non-energy use)'. Used plastic can be burnt to produce electricity or heat for heating buildings. The import and export of such non-fuel application energy is officially not considered. This is the first major methodological inconsistency. This correspondence aims at 'repairing' this inconsistency partially by delivering a 'supplementary energy trade balance' based on the lower heating values (net calorific values) of the materials imported and exported.

To my knowledge, no study has calculated the energy flows of trade for countries using the lower (or higher) heating values of these substances. In principle, the energy flows can be estimated using a life cycle assessment (LCA) approach. A big disadvantage of the LCA approach is the considerably higher uncertainty of the resulting energy flows compared to the approach applied in this study.

Every biological life requires energy. Human beings need energy directly for their body (eating) and for their housing (heating or cooling). Some materials can be used as food, fodder or as resource to produce biogas or electricity. The omission of food and fodder is a second major inconsistency of the official German energy balance. For this reason, food and fodder are included in the supplementary energy trade balance.

The mass flow of net import (m_{net}) can be calculated from the mass flows of the import (m_{im}) and export (m_{ex}).

$$m_{net} = m_{im} - m_{ex}.$$

Data about 206 mass flows of import and export of products are available free of charge from the German statistical office[2]. Thirty-three mass flows are taken directly (like cheese or fish) from the official statistics. Five mass flows were simply added up ('animals, living', 'cereals, maize grain, rice grain, products thereof', 'coffee, tea, tobacco, hop', 'flax, hemp, jute, products thereof' and 'rubber, natural and products thereof').

Six mass flows are calculated from more than 100 mass flows of the official statistics and from mass ratios ('wool, leather, fur and products thereof', 'cotton and products thereof', 'paper, wood products', 'organics fossil, plastics, vehicle', 'organics fossil, non-plastics, non-vehicle', 'chemicals renewable, in many products'). The applied mass ratios are in the range from 0.01 to 1.

For passenger cars, a total organic material content is about 25 mass per cent of the curb weight of the vehicle[3–5]. For other vehicles, the mass content of total organics is assumed to be 20% which is a little smaller than the calculated 22% for the Volkswagen New Transporter[6].

The partitioning between organics (plastics) made from fossil materials and from renewable materials is important for this study. Many exported and imported technical products contain various organic materials like plastics or engine oils. These organics are produced by the chemical industry. In 2001, the German chemical industry used around 10 mass per cent biomass resources and 90 mass per cent fossil resources as its total organic material input[7]. In most cases, I allocate 90% of organic materials (products) from the chemical industry as fossil energy ('organics fossil, plastics, vehicle', 'organics fossil, non-plastics, non-vehicle'). The remainder (10%) is assessed as renewable primary product ('chemicals renewable, in many products'). For some organics in special technical products, I also use higher or lower relative contents of renewable organics (including chemicals and plastics) than 10%.

I adjust some of the lower heating values[8–14] given in the literature for the water content, for the contents of other inorganic materials (for instance ash) and for the aggregation of materials with very different net calorific values in the official trade statistics (e.g. 'sugar and sugar beets'). The unit of the lower heating value H is petajoule per teragram (PJ/Tg = MJ/kg = kJ/g). The used net calorific values are listed in Table 1.

The average lower heating value of organic substances in passenger cars is reckoned at about 35 MJ/kg using data of a life cycle assessment study[15]. The lower heating value of plastics averages out at about 35 MJ/kg when using European Union plastics demand data[16] and lower heating values from different sources[13,14,17]. The average lower heating value of the non-fuel application biomass input into the chemical industry is about 25 MJ/kg. Chemical conversion (often by increasing the oxygen content of the material) decreases the net calorific value of the material. Therefore, the lower heating value of the portion of chemicals made from biomass is assigned to the value of 20 MJ/kg. The average lower heating value of waste plastics for the cement industry in Germany[18] is only about 22 MJ/kg because of upstream separation of plastics with high net calorific values, due to contamination with inorganic material and (intended) fillers in plastics. Chemicals other than plastics should have a lower average net calorific value than plastics because of higher oxygen content. Thus, the lower heating value for the fossil part of not-specified organic material is fixed at 30 MJ/kg.

The energy flow can be determined from the mass flows and the low calorific values, for example:

$$E_{im} = H * m_{im}.$$

The energy flow of net import (E_0) can be calculated from the energy flows of the import (E_{im}) and export (E_{ex}):

$$E_0 = E_{im} - E_{ex}.$$

In 2001, Germany exported more food and fodder than it imported ('sum food, animal, fodder, oil seed', net import –78 PJ/a). In contrast, Germany needed a net import of wood and wood products ('sum wood, paper, wood products', net import 64 PJ/a). In addition, Germany exported approximately as much other biomass in chemicals, textiles, natural fibres and other products as it imported ('sum biomass in plastics, chemicals, wool, cotton, flax, rubber', net import only 4 PJ/a). In total, the imports of all biomass were almost equal to the exports ('sum biomass all', net import –10 PJ/a). In the same calendar year, Germany

Table 1. Lower heating values *H*, mass flows (import, export and net import) and energy flows for selected items in Germany, 2001

Item	H (PJ/Tg)	m_{im} (Tg/a)	m_{ex} (Tg/a)	m_{net} (Tg/a)	E_{im} (PJ/a)	E_{ex} (PJ/a)	E_0 (PJ/a)
Animals, living	10.46	0.32	0.39	–0.07	3.3	4.07	–0.77
Milk, products thereof	2.09	1.42	4.71	–3.3	2.96	9.85	–6.89
Butter	32.43	0.14	0.05	0.08	4.39	1.73	2.67
Cheese	11.3	0.49	0.58	–0.1	5.52	6.6	–1.08
Meat, products thereof	10.46	1.71	1.54	0.16	17.84	16.13	1.71
Fish and other water animals	5.02	0.86	0.38	0.47	4.29	1.93	2.36
Oils and fats from animals	38.91	0.15	0.26	–0.12	5.65	10.31	–4.66
Eggs, parts of eggs	6.99	0.33	0.11	0.23	2.32	0.73	1.58
Fish dry, similar products	12.6	0.22	0.27	–0.05	2.75	3.41	–0.66
Food from animal	10.46	0.34	0.2	0.14	3.55	2.11	1.44
Cereals, maize grain, rice grain, products thereof	14.88	5.32	14.54	–9.22	79.12	216.25	–137.13
Leguminous plant as food (dried + not dried)	8.82	0.11	0.06	0.05	0.99	0.52	0.48
Fodder green (dried)	14.71	0.14	0.25	–0.11	1.99	3.64	–1.65
Potato and products thereof	3.76	1	2.13	–1.13	3.75	8.02	–4.27
Vegetables fresh	1	2.93	0.31	2.62	2.93	0.31	2.62
Fruit, other	2.26	2.25	0.15	2.1	5.08	0.33	4.75
Fruit, citrus	2.93	2.44	0.21	2.23	7.14	0.61	6.53
Fruit, shell, dry	10.46	0.43	0.09	0.34	4.5	0.9	3.6
Vegetables processed	1	1.84	0.31	1.53	1.84	0.31	1.53
Fruit processed	3.51	0.97	0.26	0.71	3.39	0.9	2.49
Fruit juice, vegetable juice	1	1.13	1.03	0.09	1.13	1.03	0.09
Cocoa, cocoa products	19.8	0.63	0.47	0.16	12.5	9.28	3.22
Spices (dry herbs)	14.88	0.06	0.02	0.05	0.94	0.26	0.68
Sugar, sugar beet	15.23	1.03	2.14	–1.11	15.69	32.53	–16.85
Oil seed	19.62	6.66	1.03	5.63	130.76	20.28	110.49
Oils and fats, plant, vegetable oils and fats	38.83	1.83	2.05	–0.23	71.03	79.79	–8.77
Oil seed residues	15.73	3.33	3.1	0.23	52.34	48.77	3.57
Bran, waste for fodder, other fodder	15.73	3.29	2.36	0.93	51.71	37.08	14.63
Food plant	9.25	2.35	10.46	–8.11	21.75	96.78	–75.03
Plants living, flowers	2.78	0.68	0.15	0.54	1.89	0.4	1.49
Coffee, tea, tobacco, hop	15.5	1.22	0.52	0.7	18.88	8.08	10.8
Beer	1.97	0.38	1.15	–0.77	0.75	2.26	–1.51
Brandy	10.04	0.32	0.15	0.18	3.23	1.47	1.76
Wine	2.93	1.26	0.27	0.99	3.68	0.79	2.89
Organics fossil, plastics, vehicle	35	10.44	14.26	–3.82	365.44	499.09	–133.66
Organics fossil, non-plastics, non-vehicle	30	11.88	15.78	–3.89	356.53	473.32	–116.79
Chemicals renewable, in many products	20	3.16	4.36	–1.2	63.17	87.18	–24.01
Wool, leather, fur and products thereof	21	0.55	0.36	0.18	11.46	7.65	3.81
Cotton and products thereof	17.4	1.37	0.58	0.79	23.77	10.04	13.73
Flax, hemp, jute, products thereof	16.8	0.07	0.02	0.05	1.21	0.35	0.86
Rubber, natural, products thereof	42.3	2.11	1.89	0.22	89.27	79.9	9.37
Paper, wood products	17	20.66	16.53	4.12	351.18	281.07	70.11
Wood sawn	13.16	3.13	2.62	0.51	41.16	34.5	6.66
Wood round	9.4	2.71	4.08	–1.37	25.5	38.39	–12.89
Sum of food, animal, fodder, oil seed	–	47.54	51.69	–4.15	549.58	627.45	–77.87
Sum of wood, paper, wood products	–	26.5	23.24	3.26	417.83	353.96	63.87
Sum of biomass in plastics, chemicals, wool, cotton, flax, rubber	–	7.25	7.21	0.04	188.88	185.11	3.76
Sum of all total biomass	–	81.29	82.14	–0.85	1156.29	1166.52	–10.24
Sum of all organic fossils	–	22.33	30.04	–7.71	721.96	972.41	–250.45

exported significantly more fossil energy in technical products than it imported (net export of about 250 PJ/a).

The data uncertainty has several reasons. First, the official trade statistics aggregate mass flows of materials with very different lower heating values as in ‘sugar and sugar beets’. Second, it is difficult to estimate for many technical products, the content of plastics and/or organic material. Third, the content of organic material can vary significantly between different manufacturers and different models even within one group of products such as passenger cars.

The uncertainty of mass flows (only import or export) for one specific item in Table 1 may be very big. The uncertainty of the aggregated items ‘import sum biomass in plastics, chemicals, wool, cotton, flax, rubber’ and ‘import plastics fossil, organics fossil, in many products’ can be considerably lower than the one for a specific item because of the aggregation process. The uncertainty for the net import figures of these aggregated items can reach very high values again, when import and export have a similar size and the net import is close to zero. The same uncertainty pattern can be attributed to the corresponding energy flows. In principle, the uncertainty of the energy flows should be a little higher than one of the mass flows. This is because of the additional uncertainty of the lower heating values necessary for the calculation of the energy flows.

The net import energy flows for biomass and for fossil organics (including plastics) calculated in this study are small (0.1–1.7%) compared to the official total primary energy flow (gross inland energy consumption) of Germany of about 15 Exajoule per year (EJ/a). But the import and export energy flows of these items reach 5–8% of the 15 EJ/a.

With this supplementary trade energy balance, the official energy balance of Germany can be expanded. If only the energy flow for fossil energy in technical products should be added, then further adaption of the methodology of the German energy balance is necessary. If the energy flow for the biomass should also be added, then the methodology has to be further modified. These modifications have to tackle the food production[19] and wood production within Germany.

The official statistics could be improved by less aggregation of data which are important for calculation of the energy flows by foreign trade. A specification of the organic mass content of the technical products (exported and imported) may also be a useful expansion of the official trade balance.

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