THE USE OF NATURAL RESOURCES IN SOCIETY

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Contents

Summary

The use of energy and material resources in society can be expressed in exergy by the use of exergy flow diagrams. These diagrams offer a unique view of society and are presented in a separate article (see Göran Wall "The Life Support Systems and Sustainable Development"). Charting these flows, the current misuse of resources in western societies becomes apparent. The future of life on our planet is a matter of increasing concern, as we are being confronted with several warnings about the growing fragility of the Earth's life support system. Expanding our understanding of life support systems and sustainable development are doubtless two of the most important issues mankind is presently facing. This issue challenges the community at large, demanding that it critically assess its objectives and agenda from the perspective of sustainability. This reevaluation applies equally to the scientific sector, maybe even more so. Present technology and social management are founded primarily on the knowledge offered by science. This calls for tremendous efforts from the scientific community at large, which is gradually adapting to the new situation. In some areas of science this calls for a change of paradigm.

This article will point out some important concepts in the description of the use of physical resources in society and ecological restrictions. These concepts and conditions offer an increased knowledge and understanding of the present situation and the basis of a new paradigm.

A vision of sustainable development was established in *Agenda 21*, an international declaration emerging from the Earth Summit held in Rio de Janeiro in 1992. In addition, the ongoing work of the *Encyclopedia of Life Support Systems* will, via the Internet, offer a living source of essential knowledge of the Earth's life support systems for humanity to live and thrive in symbiosis with nature.

1. The Energy Supply System

1.1 Energy System of Sweden in Terms of Energy

We will look at some important new concepts and apply them to the total energy conversion system of a society. Figure 1 describes the *energy flow* through Swedish society in 1971. The quality of the energy appears from the denotations of different kinds of energy. Arrows turned downwards imply losses. Hydropower is to be found in the top part of the diagram and fuel oil in the bottom part. The widths of the flows are in proportion to the energy content in each respective energy form.

Hydropower is used to generate electrical energy. The potential energy in the power plant reservoir is transformed into kinetic energy, which is further transformed into electrical energy via a turbine and an electric generator. Nuclear energy and chemical energy are also used to produce electrical energy. This transformation takes place in condensing power plants and in combined power and heating plants. In the combined power and heat plant, heat is also extracted at a low temperature through a so-called back-pressure process (see Figure 8 of Göran Wall, "Exergetics"). Thus, all production of electrical energy takes place within the sector "Conversions in power plants." The electrical energy is then directly used, partly in industry, e.g. in electric steel furnaces and in electrolysis, partly as lighting and for electric domestic appliances. As we see from the diagram most of the electrical energy is used within industry to run machinery, i.e. the electrical energy is reconverted into mechanical energy. An increasingly greater part of the electrical energy is used in electric heating, partly as low temperature heat for space heating, partly as high temperature heat in industry.

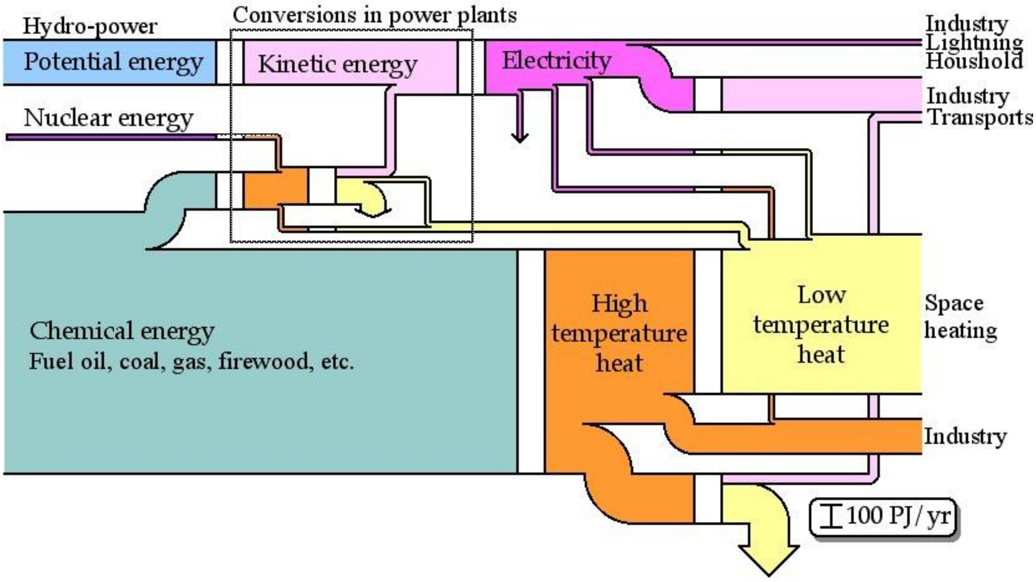

Figure1: Energy conversion system in Swedish society 1971 in energy units

The conversion of chemical energy into high temperature heat completely dominates the diagram. Fuel oil, coal, gas, waste, and firewood are burned in order to produce heat. Most of the high temperature heat is then converted, via a heat exchanger, into low temperature heat that is used for space heating. District heating and electric heating further contribute to this space heating. Part of the high temperature heat is used in industry, especially within the processing industry (the iron and steel works, and the pulp and paper industry). Within the steel industry, large quantities of coal are used, and within the pulp industry, large quantities of timber waste are used. The rest of the high temperature heat is used for transportation. Of the conversion of petrol and oil in a car engine, almost 100 percent of the chemical energy is converted into high temperature heat. About 20 percent of this heat is then further converted into mechanical energy in the car engine. Nearly half of this energy is then lost through friction in the transmission. This section is, however, not found in the diagram. The efficiency of the conversion is represented through the efficiency of the car engine, and is found at the lowest conversion level in the diagram.

The losses in the diagram are minor. Within the sector "Conversions in power plants," we find energy losses through waste heat from nuclear plants and oil condensing power plants. There are further losses of electrical energy through conductivity losses; about 10 percent of the transported energy is lost in this way. On the whole about 20 percent is lost of a total annual conversion of about 460 TWh, or about 1700 PJ. We also see that at each conversion process we have a one-to-one relation, i.e. as much energy comes in as out of the conversion process. Energy is indestructible, so all energy must remain after a conversion.

1.2 Energy System of Sweden in Terms of Exergy

Figure 2 shows an exergy diagram of the energy system above. The width of the flows is proportional to the exergy content in each respective energy form. The units of the flows are, however, the same both for the energy and the exergy flow diagrams, i.e. PJ per year. The difference now is that the width of the flows decreases radically at certain conversion processes, due to the decreasing energy quality and therefore also the decreasing exergy content. At the conversion of chemical exergy into high temperature heat, more than half of the exergy is lost. This is due to the fact that the exergy content of heat is much lower than the energy content (see Göran Wall, "Exergetics").

Further, there are heavy exergy losses at the conversion of high-temperature heat into low-temperature heat, and also at the conversion of electricity into high or low temperature heat. As the exergy content of the high temperature heat is not utilized at the conversion of high temperature heat into low temperature heat, heavy losses are suffered here too. Consequently, a heat exchanger cannot utilize the exergy loss when heat is reduced. The temperature decline in an ordinary oil furnace is thus not utilized when a flame at a temperature of about 2000 degrees Celsius is used to heat water to a temperature of perhaps 80 degrees Celsius, which is then used to heat a room to about 20 degrees Celsius. Electrical heat means that more than 95 percent of the exergy is lost at the conversion of electrical energy into low temperature heat (see Figure 8 of Göran Wall, "Exergetics"). An efficient heat pump ("an inside-out refrigerator") should be able to improve that efficiency to at least 30 percent.

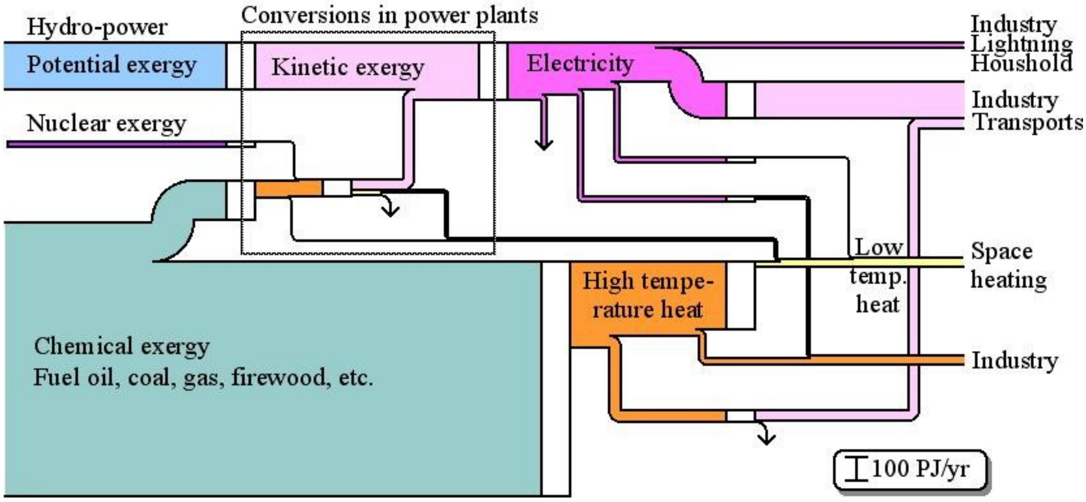

Figure 2: Energy conversion system in Swedish society 1971 in exergy units

It appears that the largest losses of exergy occur in domestic heating. As we can see on the right hand side of Figure 2, the exergy requirements in heating are quite small, and can be decreased even further through improvements in insulation and in utilizing the ventilation heat. To decrease exergy losses within heating even further, we can either use a good exergy converter such as the heat pump, or natural exergy flows such as solar heating.

The losses in the exergy flow diagram are substantial. On the whole, more than 70 percent of the supplied exergy is lost. In the exergy diagram, inflows and outflows do not balance. Exergy is always consumed in real processes, as stated above. By using exergy diagrams to describe the energy system, possible improvements can be visualized. However, the energy system is only a part of the total resource conversion system of a society. Material resources must also be added to get the complete picture of the society's resource use.

2. Exergy Use in Swedish Society

The main conversions of energy and materials in Swedish society in 1994 are shown in Figure 3, based on data from official statistics. The flows of resources go from left to right in the diagram, i.e. from the resource base to the consumption sector. Thus, the diagram basically represents the resource supply sector. The width of the flows is defined by their exergy content and the unit of the flows in J per year. Since the flows vary a great deal during the year it is preferred to use the unit J per year instead of W per year. The accuracy of the flows varies a great deal between the different areas. For the electricity system the accuracy is quite high, whereas for sectors related to agriculture and forestry we have, for obvious reasons, a different situation. In order not to make the diagram too complicated, only exergy flows exceeding 5 PJ per year are included. The inflows are ordered according to their origins. Sunlight is thus a renewable natural flow. Besides a minor use of wind power, far less than 5 PJ per year, this is the only direct use of a renewable natural flow. Harvested forests, agricultural crops, and hydropower are renewable exergy flows derived from funds, which of course are founded on the renewable natural flow of sunlight. Iron ore, nuclear fuels, and fossil fuels are non-renewable exergy flows from deposits, which are exhaustible and also carry with them toxic substances. The unfilled boxes represent exergy conversions, which in most cases represent a huge number of internal conversions and processes. The resources actually demanded in society appear as outflows on the right side of the diagram. The total inflow of resources during 1994 amounts to about 2720 PJ or 310 GJ per capita and the net output becomes 380 PJ or 40 GJ per capita. Thus, the overall efficiency of the supply sector can be estimated at less than 15 percent, which must be regarded as poor. As we shall see, some sectors are far less efficient, and in some cases, are extremely inefficient.

We will now take a closer look into each sector starting from the top of the diagram.

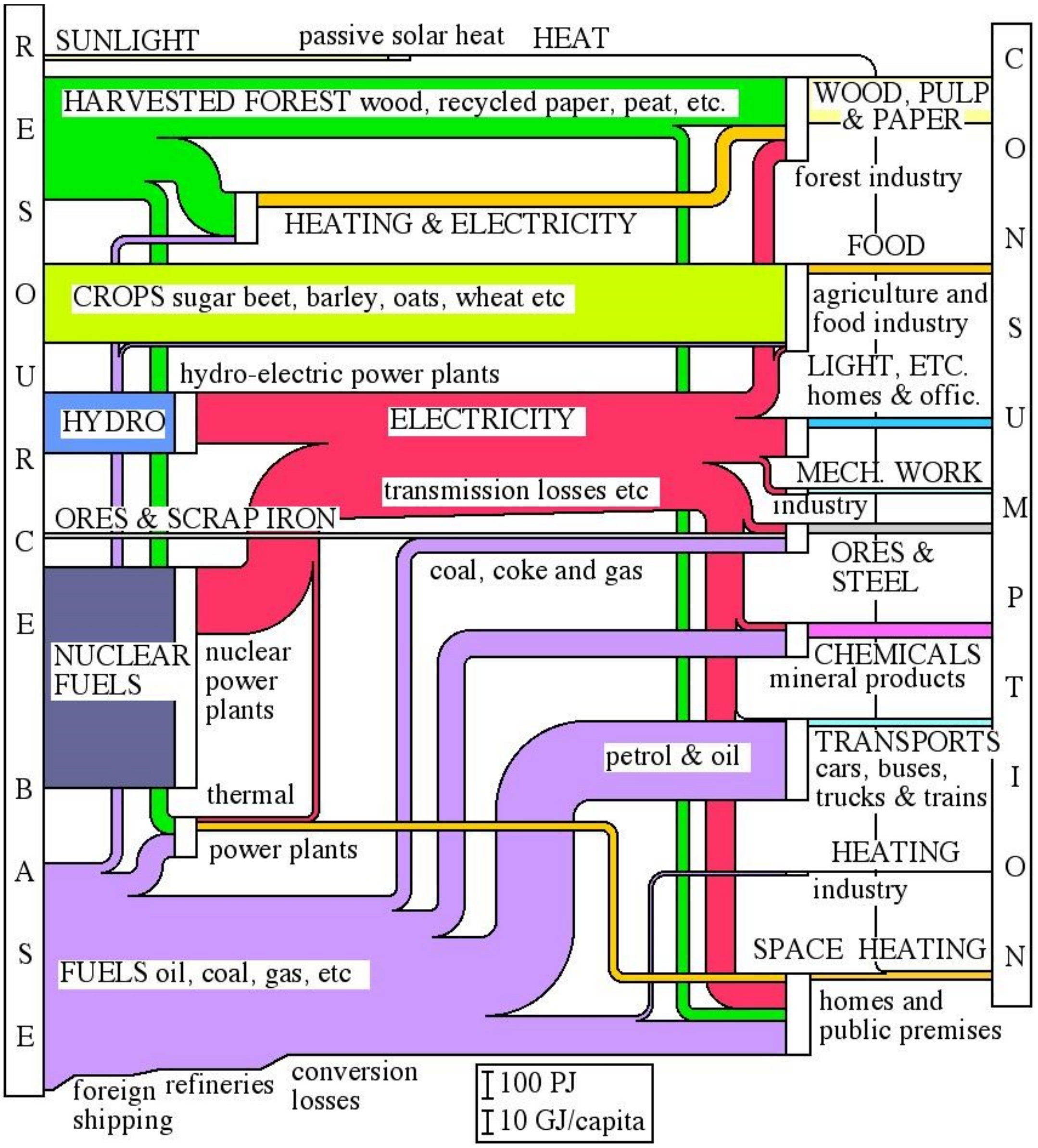

Figure 3: The exergy conversion system in the Swedish society in 1994. Total input about 2720 PJ or 310 GJ per capita and output about 380 PJ or 43 GJ per capita

2.1 Solar Heating

In Sweden, about 20 PJ of direct solar energy, is converted into heat using solar conversion systems. The total inflow of sunlight over the area of Sweden amounts to about 1 300 000 PJ per year. The converted flow of solar heat is about 1 PJ, which supplies about 5 percent of the use of heat for space heating that can be seen at the very bottom on the right in the diagram, during the heating season. The exergy content in this flow must be examined in detail. A south window lets in about 7 MJ per m^2 and per day, during the solar-heating season in Stockholm. With adequate regulation by shutters a south-facing window can be equivalent to a small heat radiator. The average solar inflow in Sweden is about 1000 kWh per m^2 and per year, or 3.6 MJ per m^2 per year in energy units. With an exergy factor of 0.93 the exergy inflow becomes 930 kWh m^{-2} per year, or 3.3 MJ m^{-2} per year. If we compare this with the average heating needs for a house we have a relation between the inflow of sunlight on the house and the average heating needs of a household of about 5:1 in energy units and 93:1in exergy units. Thus we have access to 5 times more energy or 93 times more exergy than is physically needed to keep the house comfortable. This is an example of the lack of use of available renewable resources in our society. The surfaces of our houses, i.e. the roof and walls facing the sun, must be better utilized by the energy system in the future (an example of such a house is presented in Figure 18 of Wall, "Exergetics").

2.2 Forestry and Industry Based on Forests

In forestry the stocks of timber and the raw materials derived from the forests are generally quantified in m^3 wood without bark. Wood is here used as a general term for many different kinds of timber. The exergy of wood is about 18 MJ per kilogram dry solid. The natural water content of wood is about 25 percent. With an average value of density equal to 450 kilograms of dry solid per m^3 we get an exergy of 8 GJ per m^3.

The exergy content of wood is given by the total change of chemical and "structural" exergy. The chemical exergy is the exergy stored in the material in the form of binding exergy between the atoms in a molecule. The structural exergy is the exergy or information stored in the structure of a material. This part is of great value for certain materials such as proteins or cellulose fibers. The structural exergy is well utilized when wood is used as building materials or as raw materials for the production of paper. By burning useful wood this part is utilized very badly. We optimize the utility of exergy better if we only burn structurally useless wood or paper. The structural exergy is, however, often a very small part of the total exergy content of a material but nevertheless very useful.

In 1992–1993 forest crops were used according to Table 1. Swedish timber cutting was 53.0 Mm^3 or 424 PJ. The annual growth of forests is estimated to be about 60 Mm^3 or 480 PJ. In pulp production there is a great loss of exergy due to the conversion of chemical exergy into heat during the processing of pulp. About 170 PJ of the forest crops (lignin), peat and waste together with 33 PJ of fossil fuels, gave less than 60 PJ of heat and electricity, see below. Within the wood and pulp industry, 77 PJ of electricity was also consumed. The exergy content of the outputs consisting of wood, pulp, and paper, was about 174 PJ, see Table 1.

Assortment	Mm^3	PJ
Saw-logs	25.0	200
Pulpwood	21.5	172
Fuel wood	3.8	30
Other wood	0.9	7
Total net felling	51.2	410
Cut whole trees, left in forest	1.8	15
Gross felling	53.0	424
Chips for pulp production	19.9	159
White deals	4.7	38
Red deals	4.1	33

Deals		70
Product	Mton	PJ[1]
Bleached pulp	2.4	41
Paper	2.3	39
Unbleached paper	1.1	19
Other paper	0.3	5
Pulp and paper		104

[1]17 PJ per Mton

Table 1: Calculated annual gross felling, sorted by felling-seasons and use of forest products

2.3 Agriculture and Food Production

Harvested crops are converted into food. The exergy input into agriculture and the food industry is not only solar radiation but also fertilizers, fuels and electricity. The food consists partly of plant substances such as vegetables and bread, and partly of animal substances such as milk and meat. We see that the outflow of food is very small, mainly due to losses in the production of animal products.

The agricultural land of Sweden covers at present about 2.8 million hectares. The yield is very stable from an international point of view. It varies only a few percent per year and this is compensated by trade exchanges. In Table 2, the vegetable yield in terms of exergy for the most common Swedish crops is set out.

Yield in metric tons	Mton	PJ/Mton[1]	PJ
Winter wheat	1.1702	16.0	18.7
Spring wheat	0.1747	16.0	2.8
Rye	0.1734	15.5	2.7
Barley	1.6609	15.5	25.7
Oats	0.9906	17.9	17.7
Hay	4.6275[2]	16.1	74.6
Potatoes[3]	1.0628[2]	3.5	3.7
Sugar-beets	2.3498	2.8	6.6
Winter rape	0.1	19.1	1.9
Spring rape	0.069	19.1	1.3
Winter turnip rape	0.001	19.1	0.0
Spring turnip rape	0.025	19.1	0.5
Total yield			156.2

[1]There is a large uncertainty in the precise composition of the materials, especially concerning the water content.

[2]Partly estimated

[3]Table potatoes and potatoes for processing

Table 2: Vegetable yield in Sweden 1994

The total exergy content of vegetation products is about 160 PJ. Set against this are residues such as straw and harvesting losses, about 140 PJ. The value of residues brought back into cultivation is estimated to be 30 PJ. Exergy from fossil fuels, mainly diesel fuel and fuel oil, as well as electricity, is used in agriculture, in greenhouses and in the food industry. The export and import of agricultural products is approximately equal in exergy terms. In general cereals were exported and animal-feeds were imported. The indirect use of exergy mainly in the form of fertilizers is not included here. The output from this sector is calculated here as food that is eaten solely by human beings.

Food consumption in Sweden, with approximately 8.8 million inhabitants in 1994, can be estimated in different ways. According to the recommended daily intake, the people in Sweden should consume 31 PJ with considerations for age-variation In the statistical yearbook there is stated an average of 2862 kcal per day, per person, which adds up to 38 PJ for food consumption.

2.4 Electricity from Hydropower and Thermal Power

Electricity was generated and consumed according to Tables 3 and 4.

The forest and paper industry, in its use of electricity for the manufacture of wood and wood products, consumed 6.9 PJ of exergy, and in the manufacture of paper and paper products, printing and publishing, it used 70.4 PJ, with a total for industry therefore of 77 PJ. Within food production, the use of electricity by farms was 11.8 PJ and in the manufacture of food and beverages, 8.9 PJ, for a total of 20.7 PJ. The manufacturing industry used in total about 21 PJ; 1.0 PJ in textiles, clothing and leather industries; 6.5 PJ in the manufacture of machinery and equipment; and 13.1 PJ in other manufacturing industries. Much of this electricity was used for driving machines, i.e. mechanical work. Mining and basic metal industries, mainly iron and steel, used about 40 PJ. Of that: basic metal industries and manufacture of fabricated metal products accounted for 31.5 PJ, with the remaining 8.4 PJ used in mining. The chemical industry divides into the manufacture of chemicals, petroleum, coal, rubber and plastic products, at 22.6 PJ, and the manufacture of non-metallic mineral products, except products of petroleum and coal, using 4.4 PJ. The chemical industry in total therefore used about 27 PJ. Transport, i.e. rail transport and buses, used about 9 PJ. Electricity, gas, heat and water plants used 28 PJ, and the waste treatment sector used about 3 PJ. The final and substantial portion of exergy use by society, was in electricity use by domestic households: in space heating, 105 PJ and for housing, services, mainly lighting, heating, mechanical work etc., 146 PJ.

In 1994, production of electricity from hydro, pump and wind power was 209 PJ. If we extrapolate that figure to include conversion losses of potential energy in the dam, and transformer losses at the power stations and pumping in pumping stations, the actual generated supply would become 248 PJ, which is more than the gross supply, i.e. 213 PJ, given in Table 3.

Nuclear fuel (U-235) and fossil fuels like oil and coal are also used to produce electricity. These conversion processes occur in condensing power plants and, in the case of oil, also in combined power and heating plants. A combined power and heating plant furnishes not only electricity, but also district heating by a so-called back-pressure process. We can see from Figure 3 how this flow of district heating contributes to the outflow of heating for housing and other premises.

Electricity	**TWh**	**PJ**
Hydro, pump and wind	*(gross[1])59.172*	*213.0*
Hydro, pump and wind	(net) 57.954	208.6
Nuclear	*(gross) 73.589*	*264.9*
Nuclear	(net) 70.151	252.5
Fossil fuels	*(gross) 9.876*	*35.6*
Fossil fuels	(net) 9.546	34.4
Import	6.681	24.1
Total supply	144.33	519.6
Export	6.419	23.1
Farming, forestry, etc. (1993)	3.279	11.8
Industry	48.258	173.8
Power plants etc.	7.769	28.0
Rail transport and buses	2.577	9.3
Housing (1993)	35.192	126.7[2]
Other consumers	32.209	116.0
Total domestic use	130.731	470.6
Transmission losses	7.182	25.9

[1]The difference between gross and net equals to own consumption in power stations, including transformer losses at power stations and pumping in pumping stations.

[2]Of which 104.8 PJ was used for space heating.

Table3: Electricity: generation and consumption in Sweden 1994

Industry	**TWh**	**PJ**
Mining	2.335	8.4
Manufacture of food and beverages	2.485	8.9
Textile, wearing apparel and leather industries	0.267	1.0
Manufacture of wood and wood products	1.907	6.9
Manufacture of paper and paper products, printing and publishing	19.569	70.4
Manufacture of chemicals, petroleum, coal, rubber, and plastic products	6.287	22.6
Manufacture of non-metallic mineral products except products of petroleum and coal	1.210	4.4
Basic metal industries and manufacture of fabricated metal products	8.753	31.5
Manufacture of machinery and equipment	1.806	6.5
Other manufacturing industries	3.639	13.1
Total	48.258	173.8

Table 4: Consumption of electricity by industry in Sweden 1994

The production of electricity was 253 PJ and 34 PJ respectively for nuclear and fossil fuels. The total production of electricity was 520 PJ, of which 24 PJ was net imported electricity. Of this production 471 PJ was used according to Tables 3 and 4. The rest, about 26 PJ, was lost due to electric resistance and imperfect adaptation between production and consumption, i.e. transmission losses.

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Biographical Sketch

Göran Wall is an independent researcher, specializing in exergy, sustainable development, and quality in education and management. He obtained his Ph.D. 1986 and was appointed Associate Professor (Docent) 1995 in Physical Resource Theory at Chalmers University of Technology, Göteborg, Sweden. Among his publications are more than forty papers in journals and international conference proceedings; for further information see his home page: http://www.exergy.se