Energy Use and Environmental Impacts of the Swedish Building and Real Estate Management Sector

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Summary

One of the key features of environmental policy integration in Sweden is sector responsibility. The National Board of Housing, Building and Planning is responsible for the building and real estate management sector and should, as a part of this responsibility, assess the environmental impacts of this sector. The aim of this study is to suggest and demonstrate a method for such an assessment. The suggested method is a life cycle assessment, based on an input-output analysis. The method can be used for regular monitoring and for prioritization between different improving measures. For the assessment to sufficiently cover the Swedish Environmental Quality Objectives, complementary information is needed, in particular with respect to the indoor environment.

According to the results, the real estate management sector contributes between 10% and 40% of Swedish energy use; use of hazardous chemical products; generation of solid waste; emissions of gases contributing to climate change; and human toxicological impacts, including nitrogen oxides (NOx) and particulates. Transport and production of nonrenewable building materials contribute significantly to several of the emissions. Heating of buildings contributes more to energy use than to climate change, due to the use of renewable energy sources. To reduce climate change, measures should therefore prioritize not only heating of buildings but also the important upstream processes.

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Introduction

One of the key features of environmental policy integration in Sweden is the concept of sector responsibility (Nilsson and Eckerberg 2007). This responsibility requires that environmental aspects not only are dealt with in an environmental policy context but also are mainstreamed within all policy areas. Another key feature of environmental policy integration is the introduction of Environmental Quality Objectives (EQOs; Environmental Objectives Council 2008). The 16 EQOs describe the quality and state of an environment that is sustainable in the long run; several goals are included within each objective.

As part of the sector responsibility, some governmental agencies are required to monitor the development of their sector in relation to the EQOs. The National Board of Housing, Building and Planning is responsible for the building and real estate management sector in Sweden. As a part of this responsibility, it should assess the environmental impacts of this sector. The aim of the present study is to develop and demonstrate a method for such an assessment. A requirement of the assessment was that it should take the EQOs as a starting point and evaluate the impact of the sector in relation to these. In addition, environmental impacts should be considered in a life cycle perspective, and the assessment should be easy to update. The results of this study should identify the EQOs that are most relevant for the building and real estate management sector and the significant activities in the sector from an environmental perspective.

Method Development

In analyses of the environmental impacts of a sector from a life cycle perspective, two different approaches can be used. One may be described as a bottom-up approach in which the most important products in the sector are identified. The environmental impacts of these products are then analyzed with life cycle assessments (LCAs; Guinée 2002; ISO 2006a, 2006b; Finnveden et al. 2009). The results of these product studies are then added together to form overall results for the sector. Examples of sector analyses based on a bottom-up LCA approach include studies of the forestry and metals industries in Finland (Seppälä et al 1998, 2002) and an international study of the information and communication sector as well as the entertainment and media sectors (Malmodin et al. 2010).

Another method may be termed a top-down approach and is based on input-output analysis (IOA; Engström and Wadeskog 2006; Engström et al. 2007). IOA is a well-established analytical tool within economics and systems of national accounts (Miller and Blair 1985; UN 1999; Suh 2009) that use a nation or a region as the object of the study. The input-output matrices describe trade-off between producers and users. Researchers can apply IOA to include environmental impacts by adding emissions coefficients to the monetary input-output tables (e.g., Lave et al. 1995; Joshi 1999). This approach uses environmental data that are allocated by industry and therefore linked directly to the production levels of the different industries. Environmental data are collected in the Environmental Accounts, a satellite accounting system linked directly to the National Accounts (UN 1993, 2003). In this approach, indirect impacts from upstream can be traced, calculated, and added to the direct and downstream impacts. Because these indirect impacts can be included, IOA can be used for life cycle studies. Product-based LCAs can also be combined in a number of ways with IOA-based LCAs; these result in different types of hybrid approaches (Suh and Huppes 2005).

In this study, we chose a top-down approach; the bottom-up approach would have been problematic in this case, as the sector includes many products, materials, and services. Collection of updated LCA data for all these products, materials, and services was practically unfeasible. This study may be described as an LCA of the building and real estate management sector in Sweden, based on an IOA performed with data from the Swedish System of Environmental and Economic Accounts.

System Boundaries and Collection of Data

System boundaries included the direct impacts from the building and real estate management sector and the indirect impacts from upstream processes (e.g., from production and transportation of building materials) and downstream processes describing how different products and services from the building and real estate management sector are used in other sectors. Thus, impacts were included from buildings used in, for example, other industries that buy building and construction products and services from the buildings and construction industries.

Regarding the emissions associated with heating buildings, two different systems boundaries were used: one in which emissions from production of heat and electricity used for heating were included, and another one in which they were excluded. In this way, the importance of heating the buildings could be illustrated.

The building and real estate management sector was divided into three subsectors:

- Construction of buildings (termed "buildings" below), including the construction of buildings and associated downstream activities as well as all upstream activities, such as the production of building materials and the transportation services used for the construction of buildings
- Other types of constructions (termed "constructions" below), including the production of constructions other than buildings (e.g., roads) and their associated downstream and upstream activities
- Property management (termed "management" below), including heating, maintenance, and services associated with property management and their associated upstream and downstream activities.

The IOA was based on the official 2005 input-output (IO) tables from Statistics Sweden.[1] All results, downstream and upstream, are published on a two-digit NACE (Nomenclatur générale des activités économique dans les Communautés Eurpéennes) level due to confidentiality problems. The calculations were, however, made with the complete product and industry tables. All fuel inputs and air emission data from the Environmental Accounts were at the same level of aggregation, whereas emissions to water, chemical use, and generated waste had to be analyzed on a coarser level due to lack of disaggregated data. All data and other IO-type results and documentation can be found at www.mirdata.scb.se.

All upstream results for energy use and emissions to air were calculated for domestic effects plus effects in other countries from products imported to Sweden. This was done according to the simple "as if in Sweden" assumption—that is, the assumption that what Sweden imports is instead produced in Sweden. Earlier studies indicate that this assumption typically underestimates some emissions (e.g., carbon dioxide [CO_2]), whereas other emissions may be overestimated (Statistics Sweden 2002). The downstream results were calculated only for domestic effects.

To divide the building and real estate management sector into the three subsectors—buildings, constructions, and management—we needed to disaggregate the regularly reported data. We did this by using a mix of engineering data and by assuming proportionality between inputs and value added and between outputs and gross investments. If the assessment were to be done on a regular basis, the disaggregation key would need to be regularly updated.

For the analysis, the following data were used (see also work by Palm et al. [2006] for more background on these data):

- Total energy use, renewable and nonrenewable
- Emissions to air of CO_2; nitrogen oxides (NO_x); sulphur dioxide (SO_2); methane (CH_4); carbon monoxide (CO); nitrous oxide (N_2O); ammonia (NH_3); non-methane volatile organic compounds (NMVOC); and particulates from stationary sources, from mobile sources, and from certain industrial processes
- Use of chemical products classified as hazardous
- Emissions to water of biochemical oxygen demand (BOD), chemical oxygen demand (COD), cadmium (Cd), mercury (Hg), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb), zinc (Zn), phosphates, and nitrogen
- Total amounts of solid waste and hazardous solid waste.

All these data are collected regularly within the framework of the Environmental Accounts by

Statistics Sweden. For this study, most data are from 2005. Regarding the use of chemical products, production of solid waste, and emissions to water, no data were available for the management subsector, so the data only relate to the buildings and constructions subsectors. This is potentially an important data gap that limits the conclusions that can be drawn for the sector.

The energy system in Sweden is not typical for most other countries. Approximately one-third of the energy comes from renewable sources (IVA 2009). The electricity is mainly produced from hydro and nuclear power, and district heating is primarily produced from biofuels (IVA 2009). The import of electricity varies between years and typically constitutes 1% of the use or a little more.

The environmental impact from the production and use of energy is calculated in the same way as the environmental impact from other products used in the sector. By combining information on fuel inputs and fuel-specific emission factors from the Environmental Accounts, we can calculate direct emissions from all industries. The indirect emissions from producing products that are used by the industry are then added through the IOA. The environmental impacts from electricity production thus include direct emissions from production of electricity as well as upstream impacts from production of fuel and other inputs.

Through the IOA, all building materials were included in the analysis. The environmental impacts listed above were included from the production and extraction of the materials as well as transports. The most important sectors contributing to each environmental impacts category can be identified.

Impact Assessment

To identify the most important environmental interventions from the list above, we used life cycle impact assessment methods. To compare emissions contributing to the same impact category (e.g., climate change or human toxicity), we employed characterization using the CML baseline method (Guinée 2002). The relative importance of the sector was estimated by normalization, in which the results for the sector were compared with the total results for Sweden. To compare the importance of different impact categories, we used three weighting methods: Ecotax06 (Finnveden et al. 2006), the default values of Ecoindicator (Goedkoop and Spriensma 2000), and EPS (environmental priority strategy) (Steen 1999). The Ecotax06 method has two versions, min and max; for some impact categories, minimum and maximum values are used, and a range of results is given. An intervention was considered as important for the sector if it contributed to more than 10% of Sweden's total impact according to the normalization or more than 10% of the total impact of the sector according to any of the weighting methods.

Checklist for Environmental Quality Objectives

It should be noted that the quantitative data from the IOA do not include all relevant environmental interventions—for example, land use. On the basis of the EQOs, we therefore prepared a checklist and compared it with the data provided by the IOA, and we sought additional information on aspects that were not included in the IOA. We created the checklist in discussions with a reference group consisting of stakeholders from the sector and governmental agencies to identify the relevant EQOs for the sector. This checklist is further described in the *Results* section.

Results

Environmental Quality Objectives Relevant to the Building and Real Estate Management Sector

The following EQOs were determined relevant for the sector:

- Reduced climate impact
- Clean air
- Natural acidification only
- A nontoxic environment
- A protective ozone layer
- A safe radiation environment
- Zero eutrophication
- Good-quality groundwater
- A good built environment.

Of these EQOs, reduced climate impact, nontoxic environment, and good built environment were considered especially relevant. The latter contains several subgoals of relevance, including energy use in building, generation of solid waste, and indoor health impacts (e.g., ventilation and traffic noise). Some of these EQOs, such as reduced climate impact, are fairly well covered by the data provided by the IOA, whereas others, such as a good built environment, are only partly covered. For the EQO of a good built environment, data exist on some of the subgoals—for example, on energy use and generation of solid waste—whereas data on indoor health aspects are largely lacking in the Environmental Accounts. The EQOs of a protective ozone layer, a safe radiation environment, and good-quality groundwater are not covered by the IOA, and estimations of how the building and real estate management sector contributes to these EQOs would require complementary information.

The following EQOs were determined as less relevant for the sector: flourishing lakes and streams, a balanced marine environment, flourishing coastal areas and archipelagos, thriving wetlands, sustainable forests, a varied agricultural landscape, a magnificent mountain landscape, and a rich diversity of plant and animal life. Together with the EQOs listed above as relevant for the sector, these form the complete list of EQOs.

The most important findings for each of the EQOs that were considered relevant for the sector and for which data were available are further described below. We present emissions related to the total amount of emissions on a national level to show the relative importance of the building and real estate management sector in relation to other sectors regarding each type of emission. Such calculations are a form of normalization. Normalization results are summarized and the relative importance of different emissions is further elaborated in the section *Determining the Most Significant Environmental Interventions and Sector Activities*.

Reduced Climate Change

Table 1 presents results for emissions contributing to climate change. The total results for the sector are 11.4 megatonnes (Mt) CO_2-equivalents (CO_2-e) excluding emissions from heating of buildings and 15.6 Mt including emissions from heating.[2] The Swedish population is approximately 9 million, so these numbers correspond to about 1.3 and 1.7 tons CO_2-e/capita. The emissions correspond to 16% and 20% of the total Swedish emissions, respectively, according to the Environmental Accounts. Emissions from mobile sources (e.g., transportation) account for 42% or 31% of the CO_2 emissions, depending on whether emissions from heating of buildings are included. Among the most important upstream sectors contributing to climate change are production of nonmetallic mineral products (e.g., bricks and cement), which contributes 2 Mt of the CO_2 emissions. Production of metals, land and sea transports, and production of heat and electricity are also important, contributing 0.6, 0.5, and 0.7 Mt of the CO_2 emissions, respectively.

Table 1 Yearly emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) contributing to climate change from the building and real estate management sector in Sweden, expressed as kilotonnes carbon dioxide equivalents (kt CO_2 equivalents)

Emission	*Total (excl. heating)*	*Total (incl. heating)*	*Buildings*	*Constructions*	*Management (excl. heating)*	*Management (incl. heating)*
CO_2	9,200	13,000	3,400	1,900	3,900	7,800
CH_4	1,300	1,400	120	46	1,100	1,300
N_2O	900	1,100	270	150	490	710

Note: excl. = excluding; incl. = including.

Table 2 Yearly emissions to air of nitrogen oxides (NO_x), sulfur dioxide (SO_2), nonmethane volatile organic compounds (NMVOC), carbon monoxide (CO), and particulates in kilotonnes (kt)

Emission	*Total*[a]	*Total*[b]	*Buildings*	*Constructions*	*Management*[a]	*Management*[b]
NO_x	**33.4**	**39.8**	12.2	6.5	14.7	21.1
SO_2	**10.3**	**14.2**	4.1	1.3	4.9	8.8
NMVOC	**9.6**	**11.1**	3.1	2.6	3.8	5.3
CH_4	**61.8**	**63.6**	5.6	2.2	54.1	55.8
CO	**38.3**	**54.4**	11.8	10.1	16.5	32.5
Particulates $< 2.5\ \mu m$	**6.4**	**8.0**	2.6	1.4	2.4	4.1
Particulates $< 10\ \mu m$	**8.2**	**10.3**	3.4	1.6	3.2	5.3
Particulates total	**10.5**	**12.7**	4.4	2.0	4.0	6.3

[a]Excluding emissions from heating of buildings.
[b]Including emissions from heating of buildings.

Clean Air

Of relevance for the clean air target are emissions of NO_x, SO_2, CO, CH_4, NMVOC, and particulates (table 2). For most of these parameters, the sector contributes between 5% and 10% of the total emissions in Sweden. Exceptions are particulates and methane, for which the sector contributes 14% and 23%, respectively. These figures increase by up to 4% if emissions from heating are also included. Emissions of NMVOC are the largest contributor to the creation of photo-oxidants. The most important upstream processes for NO_x are sea and land transports, which contribute 12 kilotonnes (kt) NO_x. For emissions of NMVOC, the most important upstream processes are production of fuels and forestry as well as production of chemical products. These processes contribute 1.5, 0.8, and 0.5 kt NMVOC. For emissions of particulates, the most important upstream process is production of nonmetallic mineral products, which causes emissions of 3.3 kt particulates.

Only Natural Acidification and Zero Eutrophication

In relation to acidification, emissions of NOx are somewhat more important than emissions of SO_2. Also, for eutrophication, emissions of NOx seem to be the most important parameter.

A Nontoxic Environment

The use of hazardous chemical products in the buildings and constructions subsectors is 1.2 Mt, which corresponds to 16% of the Swedish use of hazardous chemical products. In particular, the production of nonmetallic mineral products is responsible for this use. The nontoxic environment EQO is only partly covered by the IOA through data on the use of hazardous chemical products and partial emission data on some toxic compounds for the buildings and constructions subsectors. Detailed information about the use of specific compounds, the amounts already present in buildings and constructions, and emissions from these are lacking, however. Furthermore, data on the use of hazardous chemical products and the release of metals were only available for the buildings and constructions subsectors, not for management.

A Good Built Environment

The use of renewable and nonrenewable energy in the buildings and real estate management sector is presented in figure 1. The energy use in this sector is 60 terawatt-hours (TWh; approximately 215,000 terajoules [TJ]) excluding heating[3] and 176 TWh (approximately 630,000 TJ) including heating. These numbers correspond to 10% and 28% of the total energy use in Sweden. Besides production of heat and electricity, which uses 22,000 TJ, the most important upstream processes are production of materials from

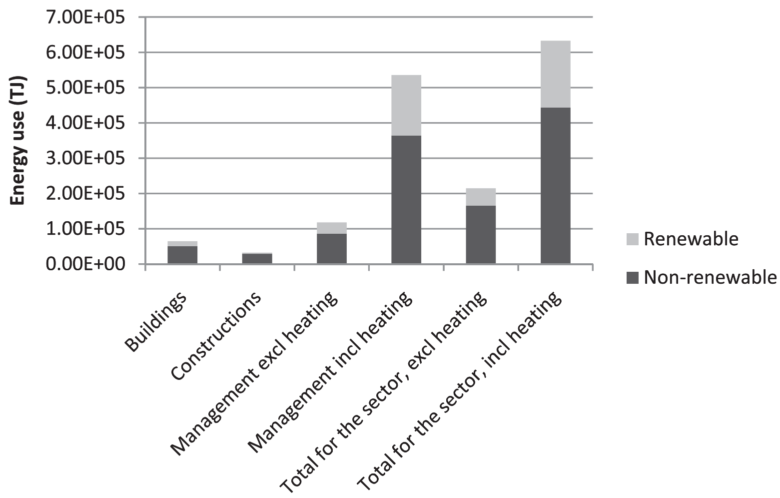

Figure 1 Energy use in terajoules (TJ) in the building and real estate management sector. Excl = excluding; Incl = including.

wood, nonmetallic minerals, and metals, which use in total 38,000 TJ.

The production of solid waste from the buildings and constructions subsectors is 32 Mt, of which 1 Mt is classified as hazardous. These numbers correspond to 27% and 40% of the total Swedish amounts, respectively. Regarding the total amount of waste, the most important upstream activity is mineral production, whereas production of metals is most important for the production of hazardous solid waste.

Human health impacts from indoor environments in Sweden have been reviewed (Malmqvist 2008), and some of the results are summarized here. One of the subgoals of this EQO concerns traffic noise. Approximately 10% of Swedes live in houses where norms concerning traffic noise are exceeded (Swedish EPA and Statistics Sweden 2000). Sleeping disturbances from traffic noise may lead to fatigue, stress, hypertension, reduced working ability, and so on. Moreover, it is estimated that 200 to 800 building-related cases of lung cancer from radon exposure occur each year (Pershagen 1993). Damp buildings have been noted as a risk factor for the unspecific "sick building symptom" (Bornehag et al. 2001). Approximately 1,000 cases each year of children's asthma in Sweden could be caused by damp buildings (Bornehag et al. 2001).

Determining the Most Significant Environmental Interventions and Sector Activities

The relative importance of different environmental interventions can be compared with different weighting methods. In this work, we applied three methods: the Ecotax, EPS, and Ecoindicator methods. Results for the Ecotax method are presented in table 3. According to the Ecotax method, climate change is the most important impact category for the sector. This is the case regardless of whether heating is included or excluded. Human toxicity may also be significant, but this depends on the assumptions made concerning what substances dominate in the NMVOC sum parameter. The IOA data are not detailed enough to allow any conclusions on this question. In addition, NMVOC, NOx, and particulates are important. The EPS method found that climate change and emissions of CO_2 are the most important aspects. Conversely, the Ecoindicator method found NOx to be the most important emission. This contradiction is rather typical of these weighting methods. The EPS method highly values climate change and resource use, whereas the Ecoindicator puts the highest values on inorganic air pollutants (Finnveden et al. 2006).

Table 3 Results for the weighting method Ecotax in the minimum and maximum versions expressed as million Swedish kronor (MSEK)

Environmental impact category	*Unit*[a]	*Result*	*Weighted result, max (MSEK)*	*Weighted result, min (MSEK)*
Climate change[b]	Mt CO_2 eq	12	12,000	12,000
Acidification	Tonnes SO_2 eq	36,000	640	640
Eutrophication	Tonnes PO_4^{3-} eq	6,300	180	180
Human toxicity	Tonnes 1,4-DB eq	54,000	27,000	80
Aquatic freshwater toxicity	Tonnes 1,4-DB eq	1,700	220	110
Aquatic marine toxicity	Tonnes 1,4-DB eq	810,000	720	0.016
Terrestrial ecotoxicity	Tonnes 1,4-DB eq	3.0	0.56	0.54
Photochemical oxidants	Tonnes C_2H_2 eq	2,800	2,400	240

Note: Impacts from heating of buildings are excluded. 1 SEK ≈ 0.1 euro.
[a]Megatonnes (Mt) carbon dioxide equivalents and tonnes sulfur dioxide equivalents, phosphate equivalents, 1,4-dichlorobenzene equivalents, and acetylene equivalents.
[b]Global warming potential (GWP 100).

The normalized results show that the sector contributes significantly to the emissions on a national level, for several of the emissions covered by the IOA (table 4). Normalization results are only reported here for the interventions that are considered most important, because they score high either in the normalization or in the weighting.

Conclusions and Reflections

In this study, we have developed a new method for assessing the environmental impacts of the building and real estate management sector. One useful aspect is that this method is based on data from the system of environmental and economic accounts, which is updated yearly. This means that the assessment can be repeated, and the environmental impacts of the sector can be monitored. The study faces different types of data uncertainties and gaps, and the method can certainly be further developed. It is, however, possible to apply this method today. The results obtained within this assessment can be used to develop indicators for monitoring the environmental performance of the sector. We are also planning a follow-up project in which we will develop time series for chosen indicators. For future improvement of the method, research must address important data gaps related to, for example, indoor environment and emissions from the use of hazardous chemical products. For the indoor environment, noise, radon, and dampness in buildings are important areas, according to earlier reviews (Malmqvist 2008).

According to the results, the building and real estate management sector is responsible for a significant part of the environmental impacts in Sweden. This finding is also confirmed by previous work (Ecocycle Council 2001; Palm et al. 2006; Carlsson and Lilliehorn 2008), and similar results have been reported internationally (Huppes et al. 2006; Tukker and Jansen 2006). Energy use, use of hazardous chemical products, generation of solid waste, emissions of gases contributing to climate change, and human toxicological impacts (e.g., NOx and particulates) are

Table 4 Normalized results for the most important interventions, not including indoor environment

Intervention	*Excluding heating (%)*	*Including heating (%)*
Energy	10	28
Carbon dioxide equivalents	16	20
Nitrogen oxides	10	12
Particulates	14	16
Use of hazardous chemical products	16	
Total waste	27	
Hazardous waste	40	

especially relevant for the sector. Table 4 indicates that the building and real estate management sector is responsible for between 10% and 40% of the total results in Sweden for these interventions.

The life cycle perspective used in this study enabled upstream processes to be included in the assessment. According to the results, several upstream processes are important for the total results of the sector. Among the most important upstream processes contributing to greenhouse gas emissions are the production of nonmetallic mineral products (e.g., bricks and cement), the production of metals, land and sea transports, and the production of heat and electricity. The most important upstream processes contributing to NOx emissions are sea and land transports and production of nonmetallic mineral products. Production of nonmetallic mineral products is the most important upstream process for emissions of particulates, use of hazardous chemical products, and total amount of waste. For emissions of NMVOC, production of fuels, forestry, and production of chemical products contribute to a large extent.

Heating of buildings accounts for a large part of the total energy use, but the use of energy in upstream processes, such as the extraction and production of building material, is also important. Regarding emissions of greenhouse gases, heating of buildings is important, but less so compared to other uses of energy, as both electricity and district heat are mainly provided by renewable energy sources and nuclear power in Sweden. This means that the results may be less typical for countries with other energy systems. The findings may, however, be seen as typical if fossil fuels have been largely phased out from the electricity system and (to a lesser extent) from the heating system.

The results can be used for prioritization of different measures for decreasing the environmental impact from the studied sector. Currently, much focus in the building sector is geared toward increasing energy efficiency during the use of the buildings (e.g., Nemry et al. 2010). This is useful because heating dominates the results for energy use. Significant potential also exists for reducing energy use (Nemry and Uihlein 2008). This study shows, however, that if the energy sources for heating are carbon-lean and the aim is to reduce climate change, then other measures must also be considered. The results here indicate that the use and production of building materials and emissions from transportation should also be prioritized. Extending the life of constructions can be one way of reducing environmental impacts. Refurbishment with the aim of reducing energy use and using materials with low environmental impacts is another strategy. Changing building materials may also be an option. For example, buildings that have wood frames instead of concrete frames reduce the emission of CO_2 (Gustavsson et al. 2006). Possibilities for recycling materials as a measure to reduce energy use and emissions should also be considered, because recycling in general reduces energy use and environmental impacts (Tyskeng and Finnveden 2010). This is relevant also for construction and demolition waste, at least if the transportation distances are limited (Ortiz et al. 2010).

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Notes

1. The two-digit version can be found at www.scb.se/Pages/ProductTables_11040.aspx.
2. One megatonne (Mt) = 10^6 tonnes (t) = one teragram (Tg, SI) ≈ 1.102 × 10^6 short tons.
3. One terawatt-hour (TWh) ≈ 3.6 × 10^3 terajoules (J, SI) = 3.6 × 10^{15} joules (J, SI) ≈ 3.412 × 10^{12} British Thermal Units (BTU).

References

Bornehag, C.-G., G. Blomquist, F. Gyntelberg, B. Järvholm, P. Malmberg, L. Nordvall, A. Nielsen,

G. Pershagen, and J. Sundell. 2001. Dampness in buildings and health: Nordic interdisciplinary review of the scientific evidence on associations between exposure to "dampness" in buildings and health effects (NORDDAMP). *Indoor Air* 11(2): 72–86.

Carlsson, P.-O. and P. Lilliehorn. 2008. *Uppdatering av Byggsektorns Miljöutredning 2000*. [Update of the building sector's environmental analysis 2000.] Stockholm, Sweden: Ecocyclic Council.

Ecocycle Council. 2001. *Byggsektorns betydande miljöaspekter*. [The building sector's significant environmental aspects.] Stockholm, Sweden: Ecocycle Council.

Engström, R. and A. Wadeskog. 2006. Environmental impact from a sector: Production and consumption of energy carriers in Sweden. *Progress in Industrial Ecology* 3: 451–470.

Engström, R., A. Wadeskog, and G. Finnveden. 2007. Environmental assessment of Swedish agriculture. *Ecological Economics* 60: 550–563.

Environmental Objectives Council. 2008. *Sweden's environmental objectives: No time to lose*. Stockholm, Sweden: Environmental Objectives Council.

Finnveden, G., P. Eldh, and J. Johansson. 2006. Weighting in LCA based on ecotaxes: Development of a mid-point method and experiences from case studies. *International Journal of Life Cycle Assessment* 11 (Special issue No 1): 81–88.

Finnveden, G., M. Hauschild, T. Ekvall, J. Guinée, R. Heijungs, S. Hellweg, A. Koehler, D. Pennington, and S. Suh. 2009. Recent developments in life cycle assessment. *Journal of Environmental Management* 91: 1–21.

Goedkoop, M. and R. Spriensma. 2000. *The Eco-indicator 99: A damage-oriented method for life cycle impact assessment. Methodology report*. Second edition. Amersfoort, the Netherlands: Pré Consultants.

Guinée, J. B. ed. 2002. *Handbook on life cycle assessment: Operational guide to the ISO standards*. Dordrecht, the Netherlands: Kluwer Academic.

Gustavsson, L., K. Pingoud, and R. Sathre. 2006. Carbon dioxide balance of wood substitution: Comparing concrete- and wood-framed buildings. *Mitigation and Adaptation Strategies for Global Change* 11: 667–691.

Huppes, G., A. de Koning, S. Suh, R. Heijungs, L. van Oers, P. Nielsen, and J. B. Guinée. 2006. Environmental impacts of consumption in the European Union using detailed input-output analysis. *Journal of Industrial Ecology* 10(3): 129–146.

ISO (International Organisation for Standardisation). 2006a. *ISO 14040: Environmental management—Life cycle assessment—Principles and framework*. Geneva, Switzerland: ISO.

ISO. 2006b. *ISO 14044: Environmental management—Life cycle assessment—Principles and framework*. Geneva, Switzerland:ISO.

IVA (Kungliga Ingenjörsvetenskapsakademien). 2009. *Energi Möjligheter och Dilemman*. [Energy possibilities and dilemmas.] Stockholm, Sweden: Kungl. Ingenjörsvetenskapsakademin.

Joshi, S. 1999. Product environmental life-cycle assessment using input-output techniques. *Journal of Industrial Ecology* 3(2–3): 95–120.

Lave, L. B., E. Cobas-Flores, C. T. Hendrickson, and F. C. McMichael. 1995. Using input-output analysis to estimate economy-wide discharges. *Environmental Science & Technology* 29: 420A–426A.

Malmodin, J., Å. Moberg, D. Lundén, G. Finnveden, and N. Lövehagen. 2010. Greenhouse gas emissions and operational electricity use in the ICT and entertainment & media sectors. *Journal of Industrial Ecology* 14(5): 770–790.

Malmqvist, T. 2008. Environmental rating methods: Selecting indoor environmental quality (IEQ) aspects and indicators. *Building Research & Information* 36(5): 466–485.

Miller, R. and P. Blair, eds. 1985. *Input-output analysis: Foundations and extensions*. Upper Saddle River, NJ, USA: Prentice Hall.

Nemry, F. and A. Uihlein. 2008. *Environmental improvement potentials of residential buildings (IMPRO-building)*. EUR 23493 EN. Seville, Spain: European Commission, Joint Research Center.

Nemry, F., A. Uihlein, C. M. Colodel, C. Wetzel, A. Braune, B. Wittstock, I. Hasan, J. Kreissig, N. Gallon, S. Niemeier, and Y. Frech. 2010. Options to reduce the environmental impacts of residential buildings in the European Union: Potential and costs. *Energy and Buildings* 42: 976–984.

Nilsson, M. and K. Eckerberg, eds. 2007. *Environmental policy integration in practise: Shaping institutions for learning*. London: Earthscan.

Ortiz, O., J. C. Pasqualino, and F. Castells. 2010. Environmental performance of construction waste: Comparing three scenarios from a case study in Catalonia, Spain. *Waste Management* 30: 646–654.

Palm, V., A. Wadeskog, and G. Finnveden. 2006. Swedish experiences of using environmental accounts data for integrated product policy (IPP) issues. *Journal of Industrial Ecology* 10(3): 57–72.

Pershagen, G. 1993. *Radon i bostäder och lungcancer: En landsomfattande epidemiologisk undersökning*.

[Radon in dwellings and lung cancer.] Stockholm, Sweden: Institute for Environmental Medicine, Karolinska Institutet.

Seppälä, J., M. Melanen, T. Jouttijärvi, L. Kauppi, and N. Leikola. 1998. Forest industry and the environment: A life cycle assessment study from Finland. *Resources, Conservation and Recycling* 23: 87–105.

Seppälä, J., S. Koskela, M. Melanen, and M. Palperi. 2002. The Finnish metals industry and the environment. *Resources, Conservation and Recycling* 35: 61–76

Statistics Sweden. 2002. *Environmental impact of Swedish trade*. Report 2002:2. Stockholm, Sweden: Statistics Sweden.

Steen, B. 1999. *A systematic approach to environmental priority strategies in product development (EPS). Version 2000: General system characteristics/models and data of the default method*. CPM Report 1999:4 and CPM Report 1999:5. Göteborg, Sweden: Chalmers University of Technology.

Suh, S., ed. 2009. *Handbook of input output economics in industrial ecology*. Dordrecht, the Netherlands: Springer.

Suh, S. and G. Huppes. 2005. Methods for life cycle inventory of a product. *Journal of Cleaner Production* 13: 687–697.

Swedish EPA (Environmental Protection Agency) and Statistics Sweden. 2000. *Naturmiljön i siffror*. [The environment in numbers.] Stockholm, Sweden: Swedish EPA and Statistics Sweden.

Toller, S., A. Wadeskog, G. Finnveden, T. Malmqvist, and A. Carlsson. 2009. *Bygg-och fastighetssektorns miljöpåverkan*. [The building and real estate sector's environmental impact.] Karlskrona, Sweden: National Board of Housing, Building and Planning.

Tukker, A. and B. Jansen. 2006. Environmental impacts of products: A detailed review of studies. *Journal of Industrial Ecology* 10(3): 159–182.

Tyskeng, S. and G. Finnveden. 2010. Comparing energy use and environmental impacts of recycling and incineration. *Journal of Environmental Engineering* 136: 744–748.

UN (United Nations). 1993. *Handbook on integrated environmental and economic accounting*. New York: Statistical Office of the United Nations.

UN. 1999. *Handbook of input-output tables: Compilation and analysis*. New York: United Nations.

UN. 2003. *Integrated environmental and economic accounting: Handbook of national accounting*. New York: Statistical Office of the United Nations.

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