VLEEM 2

MID-TERM ASSESSMENT REPORT

Annex 5

Demand for Energy Carriers – DACES

1. Introduction

Demand for energy carriers is mainly devided into three different application areas, namely the production of (bulk) materials, living and working, and travel. In the EU-15, these three sectors are quite in the same order of magnitude when looked at from an energy perspective. In Table 1.1, an overview is given of the energy use in 2000 in the EU-15.

Table 1.1. Energy demand of the main sectors for the EU-15 in 2000 [EUROSTAT, 2003].

Sector	*PJ*	PJ
Industry		11376
Domestic and tertiary		15550
Transport		12941
- by road	*10563*	
- by railway	*322*	
- by air	*1834*	
- by inland waterways	*222*	
TOTAL		39867

The industry sector accounts for approximately 30% of the energy use in Europe, the domestic and tertiary sector approximately 40%. The remaining energy use is used for (passenger and freight) transport. For the passenger transport sector, almost 80% of all kilometers were traveled by road. For freight, road transport accounts for about 75% of all mileage.

The demand for energy carriers is determined by making forecasts for the physical activity in 2100, combined with estimates for the energy efficiency of the processes related to these physical activities (so, energy use per ton of steel, energy use per kilometer traveled, energy use per dwelling for space-heating, and so on).

The total energy demand depends also on forecasts on the population and the wealth of people in the different regions distinguished in VLEEM. These data will be taken from the results from the BASES model.

2. Bulk materials – Introduction

In analyzing the future energy needs for the production of bulk materials, two major drivers are important: The amount of material produced, and the specific energy needed to produce 1 ton of material (the so-called SEC, specific energy consumption). These two factors combined together give an indication for the amount of energy that will be needed in the various regions of the world for the material production system.

In our analyses, we have included the following materials:

- Iron and Steel
- Aluminium
- Pulp&Paper
- Polymers
- Cement
- Fertilizers
- Bricks & Roof tiles
- Glass
- Wood

Finally, to link up with the material demand categories in the VLEEM model, an analysis on the shares of materials by type of application is needed. In that way, we can analyze the demand of energy for the production of packaging materials, building materials, infrastructure materials, fertilizers and other bulk materials.
The methodology for these three steps is elucidated in the next paragraph.

2.1 Methodology bulk materials

Step 1: Activity level

In order to estimate the future demand for materials, a historic analysis of the production and consumption patterns for various materials is first made. Time series for apparent consumption in the past can be derived from production and trade statistics according to the formula:

Consumption = Production + (Imports – Exports)

In order to link these consumption data for physical material use to developments in GDP and population, the consumption per capita is plotted as a function of the per capita GDP as shown in Figure 2.1. Data are collected for as many countries and regions as possible and for as many years as possible. A curve representing the best fit is then included in the graph.

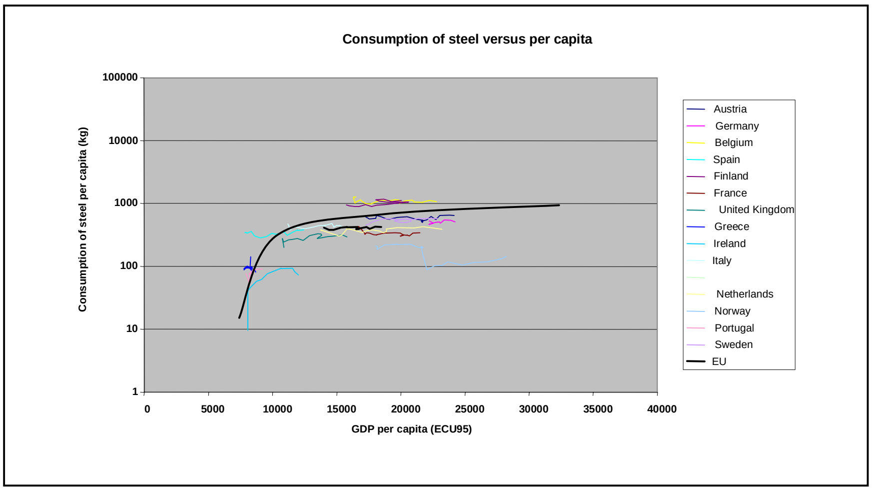


Figure 2.1: Per capita apparent consumption versus per capita income

If one assumes that no drastic changes in consumption patterns will occur in the future, the information available from this fitted curve can be combined with forecasts for GDP and population to generate projections for the future consumption of materials. For countries that nowadays have relatively low levels of material use this curve can be used directly for projections (because the relationships for high-income countries can be made use of) while, for high-income countries, the fitted curve first needs to be projected.

In the following, the use of the curve shown in Figure 2.1 for projecting the demand for materials is explained in more detail. A two-stepped approach is taken: first, the specific material consumption per capita (y axis) is determined on the basis of future GDP per capita (x axis); and second, the specific material consumption per capita (y axis) is multiplied by projected population to calculate the material use in absolute terms (e.g. in million tonnes per year).

Using projections for net trade the level of production for the materials considered can then be calculated. Next, forecasts for the shares of material use per type of application (e.g. steel production for construction, automobiles, packaging etc.) are used to estimate the demand for materials for the main types of application considered within VLEEM2 (Food/Alimentation, Shelter/Lodging and Transport). By conducting this type of calculation for all bulk materials the total material use by types of application can be projected (e.g. total material use for packaging by the year 2010).

Step 2: Specific energy use

Both the level of activity (e.g., the production volume of steel) and the specific energy requirements (in GJ per tonne of steel)) determine the future total energy use (in PJ). Having dealt with activity levels in the preceding section we now turn to specific energy use. To project its future level, first an inventory is made of results from studies on energy efficiency potentials. These studies usually reach up to 2020 to 2050. Beyond this point of time, it is hardly possible to estimate the specific energy consumption (SEC) on technological grounds.

From this point, up to 2100, a simple projection method is applied to project the specific energy use. We assume that in the period 2050-2100 $1/3^{rd}$ of the gap between the specific energy consumption in 2050 and the thermodynamic minimum can be reduced. For technologically advanced scenario’s, we then assume that of the remaining gap between the specific energy consumption in 2100 and the thermodynamic minimum, again can be reduced by $1/3^{rd}$. Graphically, this can be depicted as shown in Figure 2.2.

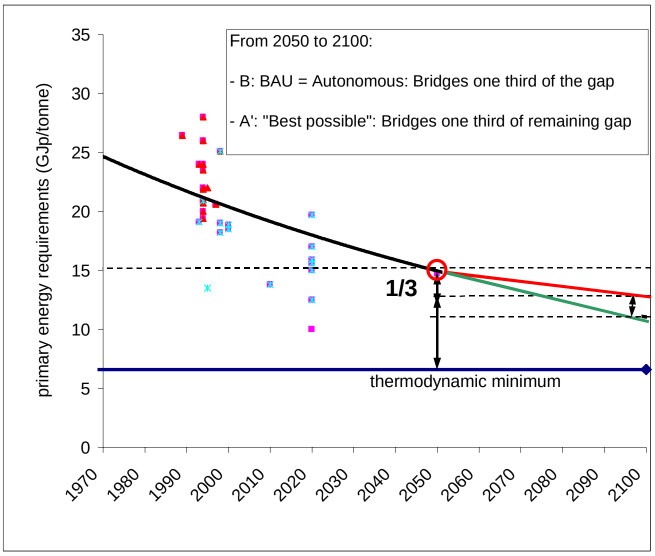


Figure 2.2: Estimating the future energy requirements for materials production

As was mentioned earlier, in the VLEEM demand model, already a link has been implemented between the information content and the specific energy use for materials. By analogy with the calibration explained earlier for information and material use, the relationship derived from Figure 2.2 can be used to calibrate elasticities between information content and specific energy use.

For this step, we have contacted sector representative organizations and used literature sources on the use of materials. By constructing historical series of these shares, an indication of the trend towards the future was analyzed. This trend has then been forecasted to the shares of materials for application for 2100. An example of this approach is shown in Figure 2.3.

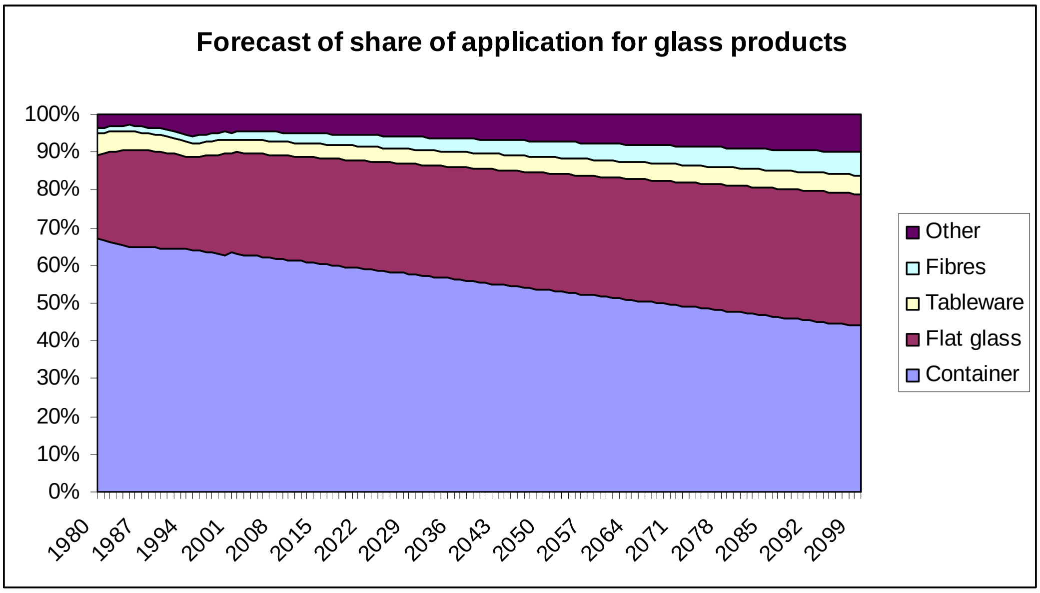


Figure 2.3. Share of materials by type of application

2.2 Bulk material studies

For the research on future energy demand for bulk materials production, we have followed a similar approach to all materials. In this report, we would like to focus on the iron and steel industry, as an example of these bulk materials. Other materials have been studied as well, and the results for these materials have been included in the appendix to this chapter.

2.2.1 Iron and Steel

Overview of the iron and steel process

Broadly the iron and steel production can be divided into 5 steps:

1. treatment of raw material
2. iron making
3. steel making
4. casting, and
5. rolling and finishing

Currently, steel is mainly produced in two routes primary steel know as integrated primary steel and secondary steel known as scrap-based mills. Primary steel production involves the mineral and coal while the secondary process involves recycling scrap along with sponge iron and electricity. Depending on the production route some of the steps are omitted thus substantially reducing the energy intensity of the overall route: integrated (steps 1-5) and minimills (steps 3-5).

Physical Production Level

The level of activity for the sectors is described as a trend relating apparent consumption per capita vs. GDP per capita. To construct such trend time series of historical data for the VLEEM regions is needed in terms of population, GDP, material production and trade of products.

The key physical indicator is the apparent consumption of the product (steel or paper, in kg). In order to project material production per region, trade (imports and exports) has to be included.

To accurately model trade a deep understanding of markets, resources, prices and other interests (governmental agreements, etc.) have to be included, to make matters more complex trade follows a dynamic changing economic environment where it is hard to quantitatively measure the effects and their impact on the global sector.

Regarding the iron and steel sector, trade has been modelled in different ways. Michaelis and Jackson (2000) keep the trade for the UK steel sector constant at 1994 levels in order to concentrate on the internal changes of the industry, Van Vuuren *et al.* (1999) model trade as one world region, Ruth (2002) mentions the use of an econometric model for the US market demand and supply, Labson (1997) describes an econometric trade model that simulates dynamics of regional production and consumption over the short to medium term (4 years). Given the found complexity in ways of modeling and the timeframe in which VLEEM operates, such detailed trade models have limited applicability.

In our case, trade is accounted in the following way: rather than keeping trade as a fix material amount, the ratio between net import (imports minus exports) and apparent consumption [units of t/t] was kept constant at 2000 ratio. The sign of the ratio expresses the importing or exporting tendency of the region, therefore added or subtracted to the apparent consumption to provide the projected production.

Historical data for iron and steel

When expressing the relationship between material consumption and wealth for the respective VLEEM regions, along with the resulting fitted curve. As expected, there is a tendency of increasing apparent consumption with wealth until a stabilization of this consumption occurs [Appendix A1]. Regions that show a clear apparent stabilization are North America, Asia OECD and Europe. At this stage the fit obtained in Appendix A1 was verified against each region for a final acceptance of the fit.

Specific Energy Indicator

For the specific energy consumption trend different studies on available technologies, best practices and potentials of technologies were used. These historical and potential values are plotted until the year 2050; thereafter the procedure described in the methodology is followed.

A technology-based development, as is our approach, can provide an idea of the tendency for energy consumption while still taking into account the thermodynamic minimum and a decreasing efficiency improvement rate with time.

The assumption of an increase in energy efficiency based on technological development is based from the noticed decline in energy intensity in the studied sectors, which could be partially attributed to governmental energy conservation programs and policies (Ma *et al.*, 2002; Worrell *et al.*, 1997; SAVE-ODYSSEE, 2003). Working from this decline and potentials obtained from other studies a technological development trend is created.

Note that this approach might still have some drawbacks in its outlook as political system uncertainties, lack of dissemination of information on energy efficiency technologies, fuel prices, capital scarce economies and other factors are not taken into account as their estimates for the time frame carry much uncertainty (Schumacher, 1998).

Assumptions and projections

Adopting such technological development trend must take into account several assumptions. Among these assumptions for the iron and steel industry are:

Thermodynamic minimum: SEC development must be limited by the process thermodynamic minimum, which is based on the Gibbs free energy for reducing hematite (Fe_2O_3), the most occurring iron-oxide, into $2Fe + 3/2O_2$. The use of Gibbs free energy represents the maximum amount of work that can be obtained when a compound is converted to it chemical elements, thus providing the absolute minimum and non-technology dependent thermodynamic minimum. This energy is approximately 6.6 GJ/t, assuming all iron can be recovered and not taking into account iron composition, and shaping into desired product. A similar approach for secondary steel, scrap process of producing steel, the energy to be applied is less than 0.1 GJ/t (de Beer, 1998).

Structural Changes: EAF and BOF: Assumption that EAF penetration world wide will increase its share up to 50% in 2100, from its current 30%, based on projected penetration (Michaelis, 2000; van Vuuren, 1999). Differences in current and potential regional EAF shares were taken into account.

Within the physical activity of the Iron & Steel sector the structure is of great importance. The two main routes for steel production are basic oxygen furnace (BOF) and electric arc furnace (EAF), where as explained electricity is used to melt and refine the steel scrap input.

Currently most of the EAF plants use scrap as input, thus avoiding the iron making step leading to much lower energy consumption. A limitation of only using scrap as input is the low quality of the steel compared to BOF (due to scrap impurities). In order to increase the quality of the EAF steel processes like DRI and smelting reduction serve as feedstock for the EAF. This has increased the share of EAF in the steel production.

It must be noted that changes and developments in steel technologies (as DRI and smelting), distinction between steel and scrap quality (high, medium, low), scrap geographic dispersion and ability to recycle steel waste are likely to alter these estimates.

Political reforms: As there are increases in governmental and world pressure on climate and energy regulations these SEC tendencies might reflect change in capital infrastructure, and possibly externalities such as political tendencies.

Specific energy consumption: Different specific energy consumption curves between industrialized and developing countries for the respective routes based on the literature potentials were created. The use of two SEC curves is intended to simulate the ‘catch up’ behaviour between world regions due to investment, technology transfer and application of new technologies, where lastly both SEC tend to convergence. The references and values used for the creation of the specific energy consumption potential trend are presented in appendix A2, and the resulting trends for industrialized and developing regions shown in A3.

Energy Projections

The energy projections for the Iron and Steel sector by regions are presented in appendix A4. It shows a continuous increment from current levels until 2050 when stabilization appears. Of the importance regions to notice are China and South Asia and the continuous decrease of industrialized regions.

2.2.2 Other bulk materials

The same approach has been used to study the other bulk materials as listed in the introduction to this chapter. The results (analysis of per capita material consumption vs per capita income; future development of the specific energy use; future energy demand for material production for various regions) are included in the appendices to this report for the materials for which they are available at the time of writing.

2.3 Materials by type of application

In the VLEEM model, the bulk materials are not included as such, but they are incorporated into various demand categories like materials for buildings, materials for infrastructure and fertilizers. Therefore, it is necessary to understand the application of the various bulk materials and to identify possible changes in these applications over time. Therefore, we have analyzed to use of the bulk materials for various application purposes based on historical data, usually available for at least a 10-year period.

For the glass industry, data was available for the period 1980-2002. The trends from the use of glass by type of application have been forecasted, and the results are shown in Figure 2.4.

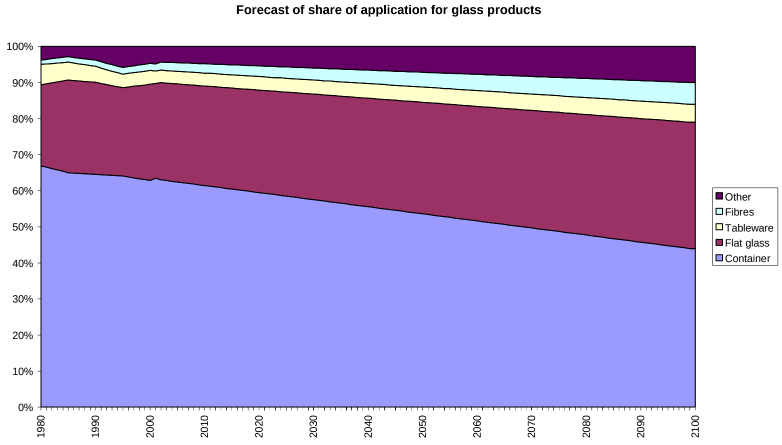


Figure 2.4: Application of glass.

3. Transportation

3.1 Freight transport

Transportation of freight has been increasing over the past decades, and is expected to keep increasing in the (near) future. For freight transport, usually the distinction between transport by air, road, rail and water is made. Inland shipping accounts for only a small part of the total transport, and is therefore left out of scope. Most products are shipped via road or in the case of high value added products, via air. Shipments overseas mainly occur for bulk materials. For the time being, we have focused on the transportation of base materials for the production of bulk materials, since the forecasts for bulk materials production were easily available from our previous research on bulk material use.

For the energy needed for transportation of base materials, we have followed a very basic approach. Current lifecycle assessment (LCA) tools include large databases on the inputs and outputs for various production processes. For most of the base materials, part of the inputs that are included in this tool, is the way the transportation of the raw materials for bulk materials production is arranged. Therefore, from the database in this tool, we have subtracted data about the basic energy use for the transportation of the raw materials needed. In the case of steel, these raw materials are coal, iron ore and limestone. The database also includes the main source of origin of these raw materials, and therefore the transportation distance is known. Together these data give insight in the need for energy for the transportation of the raw materials. For our current analysis, we have not included any other effects, like shift of origin of the raw materials and improvements in energy efficiency of transportation nodes. When using the specific energy needs for transportation and the forecasts for material production, we can give an indication for the total amount of energy needed. This is shown in Figure 3.1.

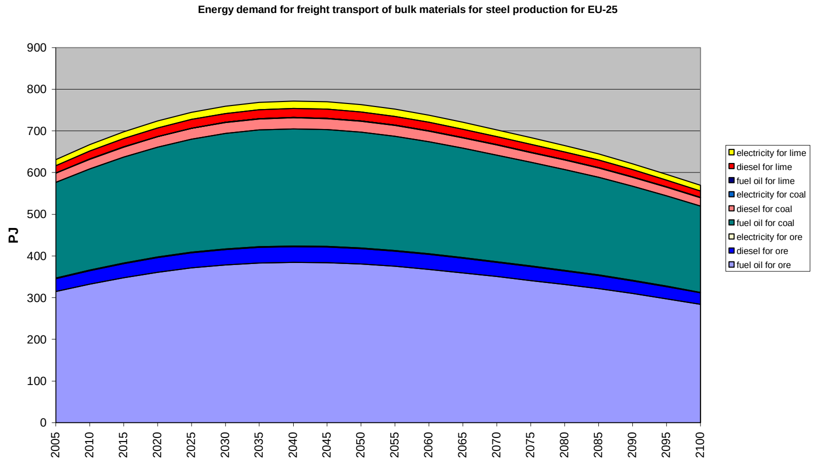


Figure 3.1: Energy needs for transporting raw materials for steel production

When using LCA data for this kind of analyses, one of the main limitations is that the data in these databases are derived from current (2000) energy consumption levels, and no information is available from these databases for long term prospects on energy use. Another limitation is that no drastic changes in transportation modes is accounted for, although this doesn't seem relevant for most bulk materials since the quantities in which they are shipped doesn't leave much space for drastic changes in transportation mode.

3.2 Passenger transport

For passenger transportation, two sets of vehicles were defined that can be used for VLEEM and link up with the methodology for energy efficiency improvements. As we have described in the section on materials, two possible trends are used to describe the specific energy requirements for material production; one that is the continuation of the forecast up to 2050, and one that accounts for additional energy efficiency improvements of 1/3rd of the gap between the SEC$_{(2100,\ \text{standard development})}$ and the thermodynamic minimum.
In the case of passenger transportation, there is a distinction between a standard development of energy efficiency in vehicles, and a more efficient development. Furthermore, different car fleets can be selected, based on preferences for the type of engine and/or the type of fuel. In Table 3.1, an overview is given on the energetic performances of these vehicles.

Table 3.1: Energetic performance of cars

CONVENTIONAL EFF IMPR

ENGINE	FUEL	ENERGY USE MJ/veh.km	TYPE of FUEL
ICE	Conv	1,74	oil
ICE	biofuel	1,74	MeOH
FCV	H2	1,30	H2
FCV	biofuel	1,39	MeOH
HYB	Conv	1,48	oil
HYB	biofuel	1,48	MeOH

ADVANCED EFF IMPROVEMENT

ENGINE	FUEL		
ICE	conv	0,98	oil
ICE	biofuel	0,98	MeOH
FCV	H2	0,73	H2
FCV	biofuel	0,78	MeOH
HYB	conv	0,83	oil
HYB	biofuel	0,83	MeOH

4. Buildings

Research on the housing sector is not yet completed. We will follow the approach as we suggest below.

The direct energy requirement for buildings can roughly be split up into three categories: electricity for appliances, energy for space heating and cooling, and hot water demand. Of these categories, especially the energy demand for space heating and cooling depends on the amount of floor space of the average dwelling. For this, an analysis of the historic development of per capita floor space versus per capita income would best fit with the methodology we have used for the materials sector. In addition, we will have to give an indication for the amount of energy needed for this floor space to have a comfortable room temperature (either through heating or cooling or both), depending on average climate information for the various regions.

From historical developments on the use of energy for space heating, large differences between countries are observed. Also, a trend towards more energy efficient space heating over this period for the countries that have an initially high energy demand for space heating can be observed, as shown in Figure 4.1

For a complete analysis of the energy demand of the future house, results from the monograph on the ‘House of the Future’ from the first phase of VLEEM, will be combined with this approach [Reisinger et al., 2002].

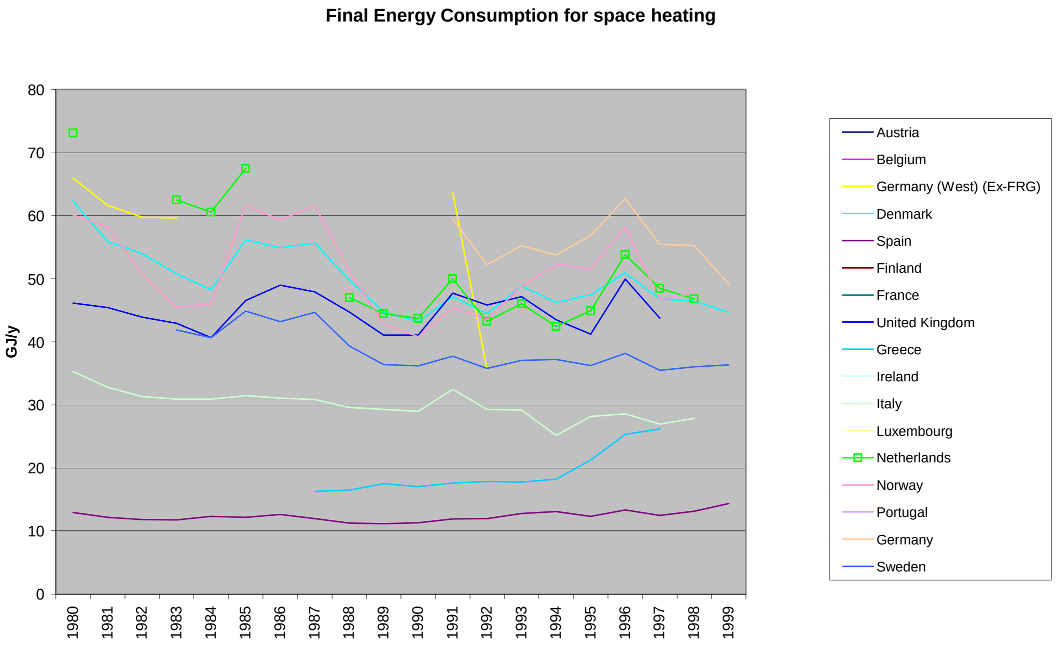


Figure 4.1: Development of energy requirement for space heating in EU countries

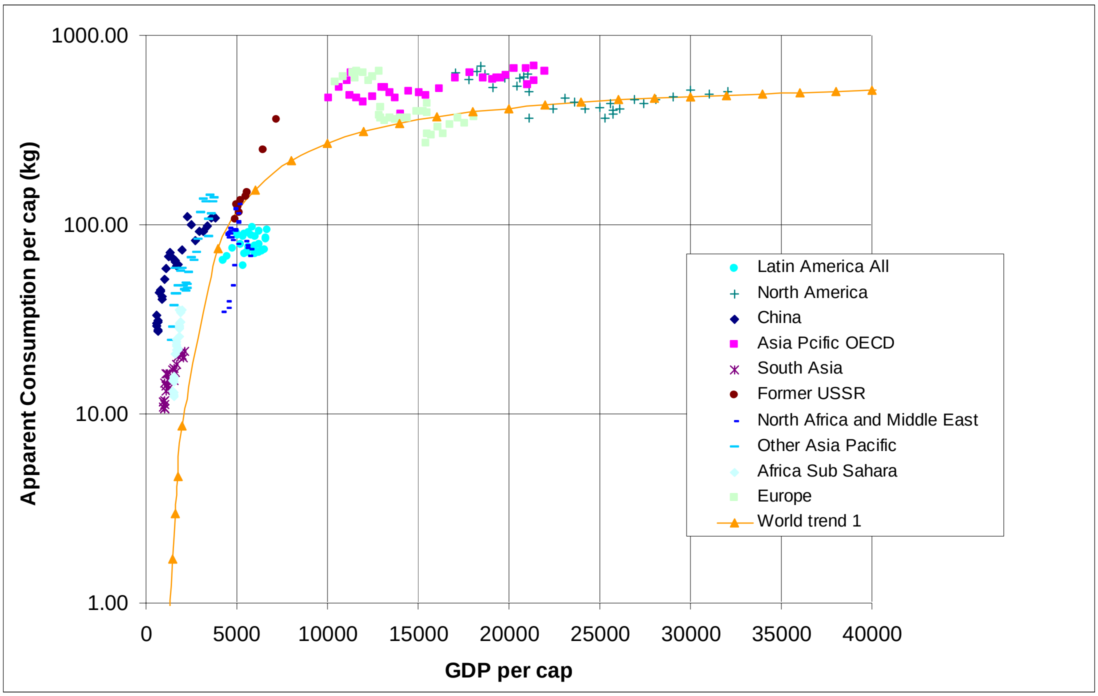
For the analysis on the amount of floor space, the relationship between per capita floor space versus per capita income, together with the amount of households and average number of persons per household (which will both be available from the VLEEM-BASES model later on) we can derive an absolute number of square meters of floor space for space heating for the various regions used in the VLEEM model.
From the DACES database, a first indication can be given for the amount of energy required for the heating requirements of dwellings. Again, this data is available in different sets of energy efficiency improvements in the future. The data is listed in Table 4.1.

Table 4.1 Direct energy requirements for dwellings

Energy service	Best practice 1999	Dwelling type A	Dwelling type B	Dwelling type C	Unit
Space heating	80	67	37	20	MJ/m^2.a
Cooling	7	7	13	13	MJ/m^2.a
Water heating	4	3	2	1	GJ/a
Appliances	1920	1015	800	580	kWh/a

For a typical house of 120 m^2, this results in an energy demand for heating (room heating and warm water) of 3300 kWh, 2200 kWh and 1400 kWh for the A, B and C types, respectively. The total energy demand is then 4300, 3000 and 2000 kWh, respectively. This is a factor 2 to 4 in terms of reduction of the energy demand compared to 2000 levels.

APPENDICES:



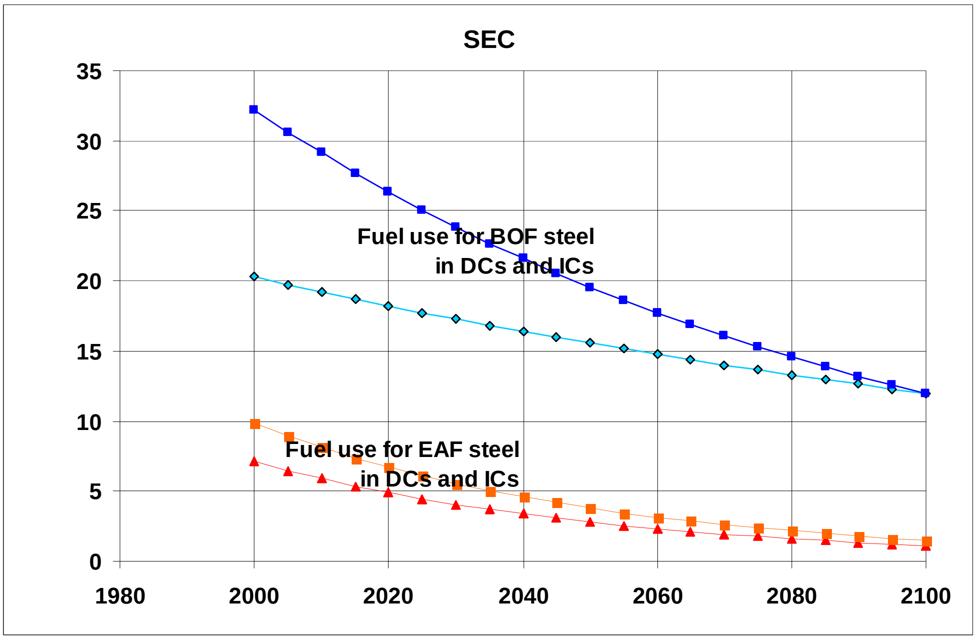
A1: Apparent consumption per cap vs. GDP per cap for the representative countries grouped under the VLEEM regions and the adjusted empirical trend.

A2: Literature review for specific energy consumption and potential potentials for integrated and secondary steel production.

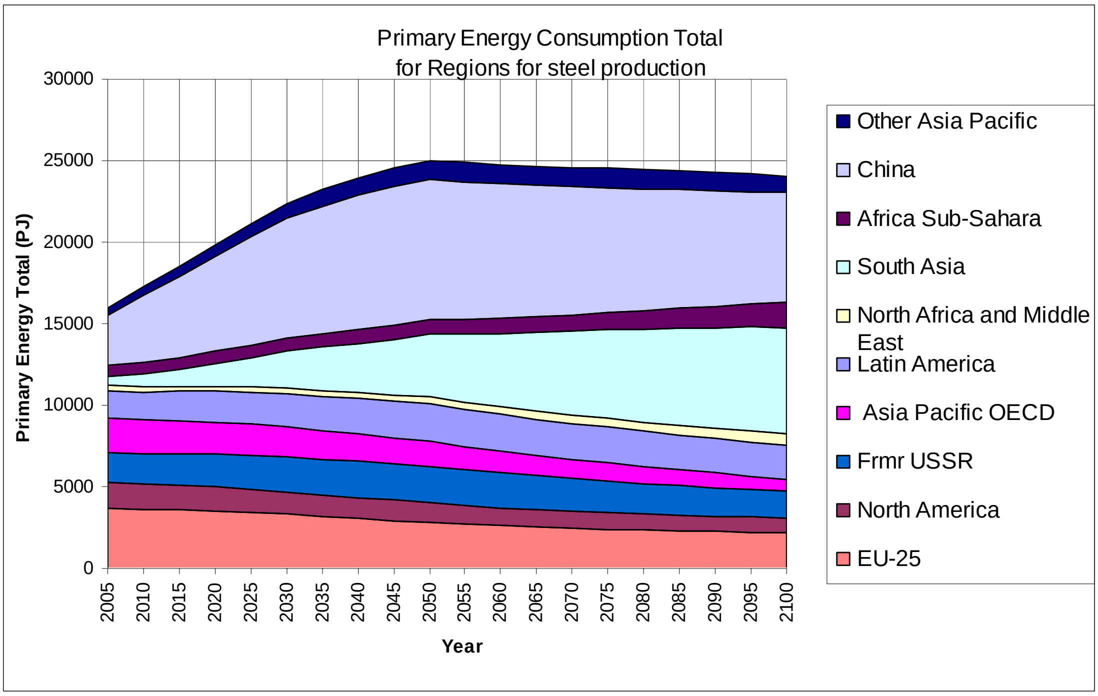
Reference	Year	Country	Integrated Steel (GJ/t)	Secondary Steel (GJ/t)
1	All	Thermodynamical minimum	6.6	0.1
	1993	All Europe	24	
	1998	Best Potential	19	7
	2020	Potential	12.5	3.5
	1994	NL	20	
		GE	21	
		FIN	22	
		SP	23.5	
		UK	24	
		CZ	26	
		BE	28	
2	1994	USA	21.8	8.5
3	1997	NL	20.6	9.7
4	1994	UK	19.4	11.6
	2020	Potential	17.0	10.4
5	1989	CAN	26.43	10.19
	2000	CAN	18.84	6.83
	2010	Potential	13.80	5.98
6	1994	US Best potential	21.13 20.90	10.4 11.0
	2000	US	18.5	8.3

7	1995	Brazil China India Mexico South Africa	23.1 36.7 37.2 22.6 44.4	18.8
8	1980	Brazil China	32.3 51.3	
	1991	Brazil China	31.7 42.4	
9	2020	Potential	15.9	6.6
	2050	Potential	14.7	4.4

Sources: 1) De Beer et al. 1998, 2) Energy and Environmental Profile of the US Iron and Steel Industry. July 1996. Prepared by Energetics for the US DOE (report), 3) DJ Gielen & AWN Van Dril, 4) Micahelis P. 2000, 5) RDD, Stelco Ind, 1993, 6) Worrell et al. Jul. 1999. 7) Price et al. 2002, 8) Worrel et al. 1997, 9) Kahrlsruhe



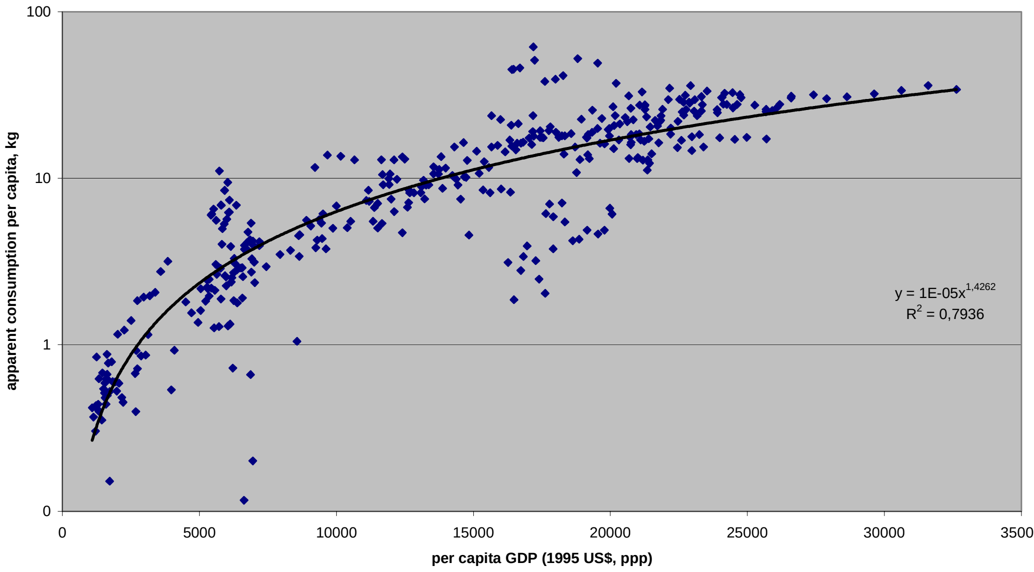
A3: Resulting specific energy consumption (GJ/t) trends for developing (upper curve) and industrialized regions (lower curve) for integrated and secondary steel routes based on the literature values from A-5.



A4: Primary Energy Consumption for steel under the BAU Scenario for the various VLEEM regions.

In the next annexes, the progress of the analyses so far is shown without any further comments. The work for determining the demand for energy carriers is split up into three parts, as mentioned in the methodology paragraph. First, an analysis of the relationship between per capita material consumption versus wealth is made, then an analysis of the development of the specific energy consumption for the production of these base materials is made. Finally, an analysis is made on the share of application by type of end-use of the materials under consideration. The first to graphs are shown per page for the bulk materials, the application by type of end-use graphs are then shown at the end. These graphs give an overview of the work that is done. Missing graphs represent research still needed for completing this analysis.

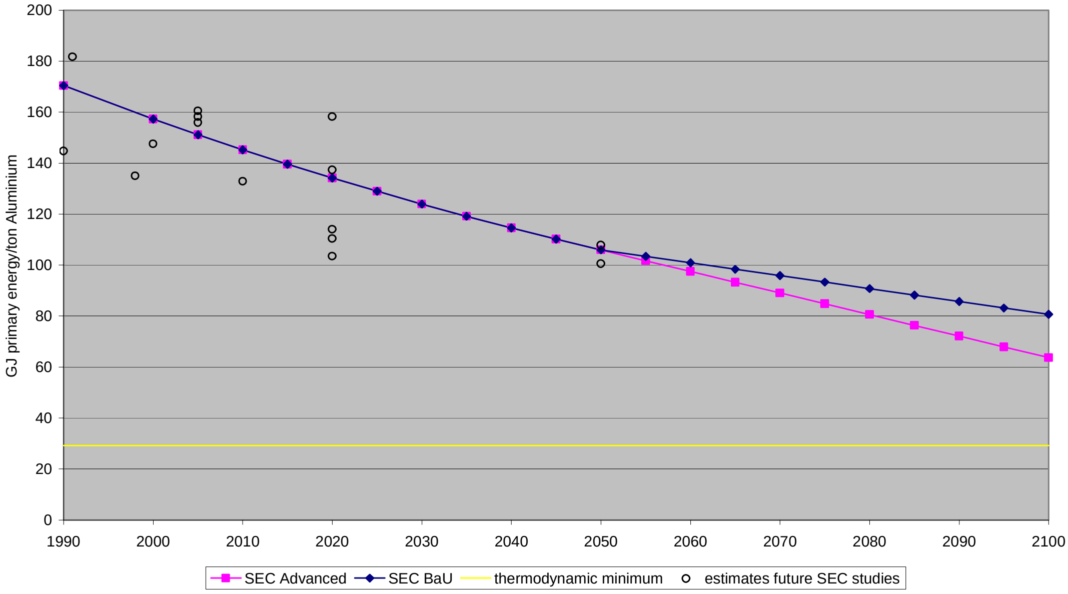
Apparent per capita consumption versus per capita income

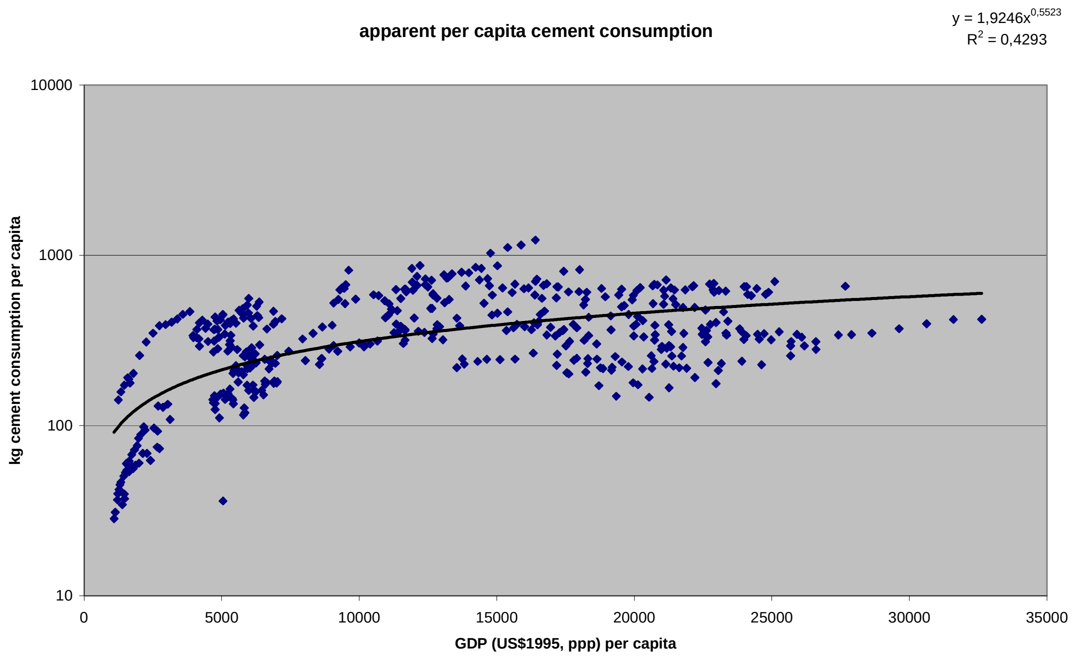


A5: Per capita aluminium consumption versus wealth

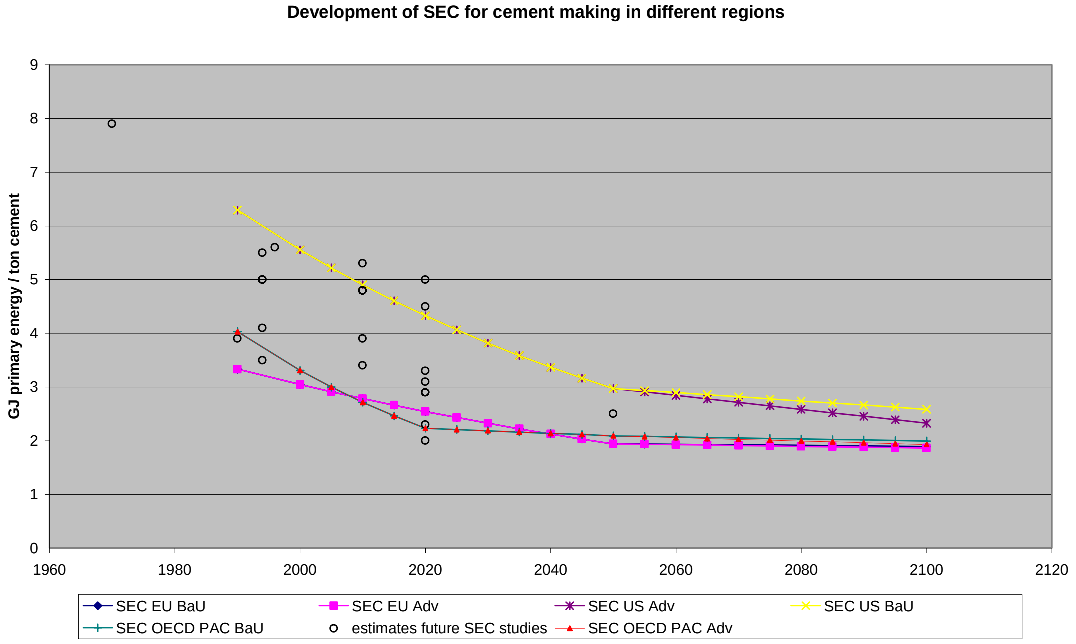
A6: Development of Specific Energy Consumption for Primary aluminium production

Development of Specific Energy Consumption for primary Aluminium consumption

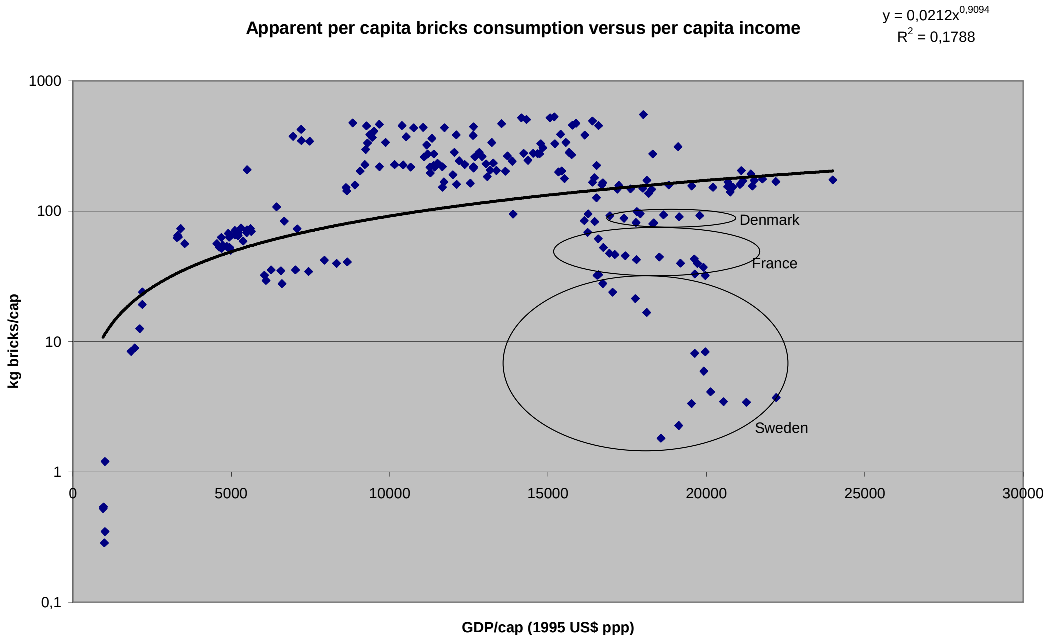




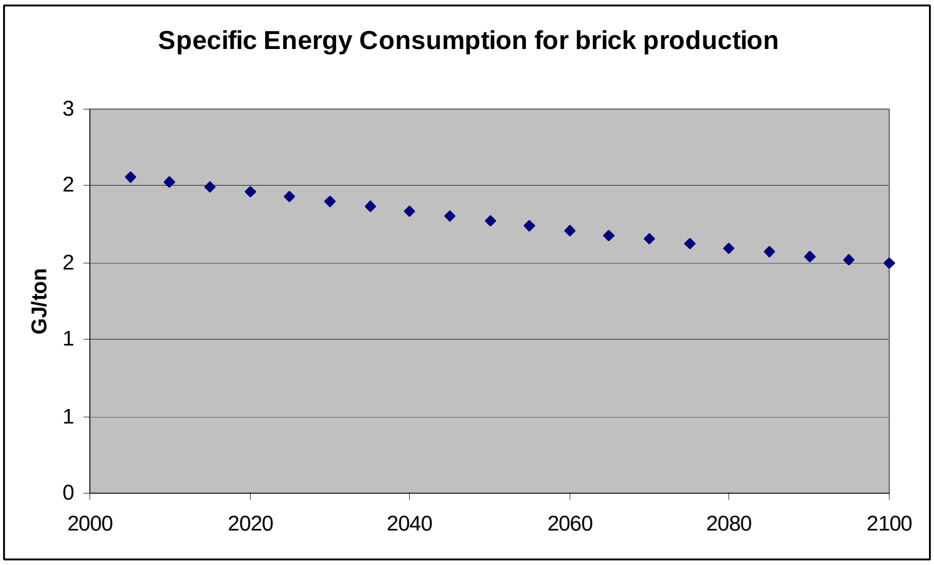
A7: Per capita cement consumption versus wealth



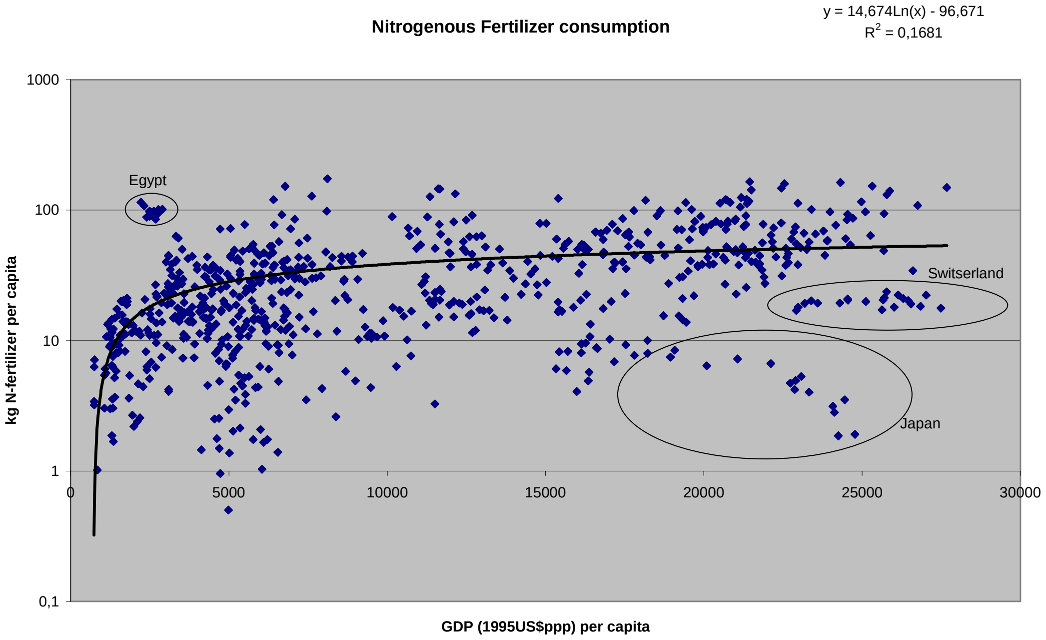
A8: Development of Specific Energy Consumption for cement production



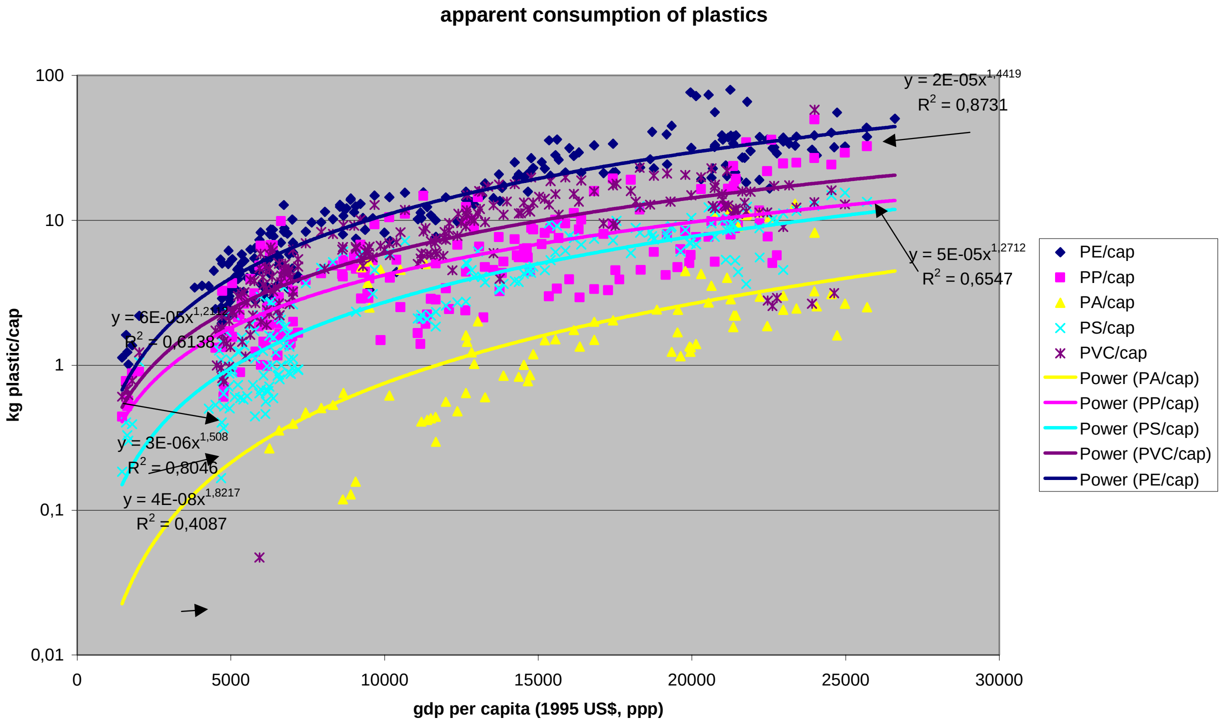
A9: Per capita brick consumption versus wealth



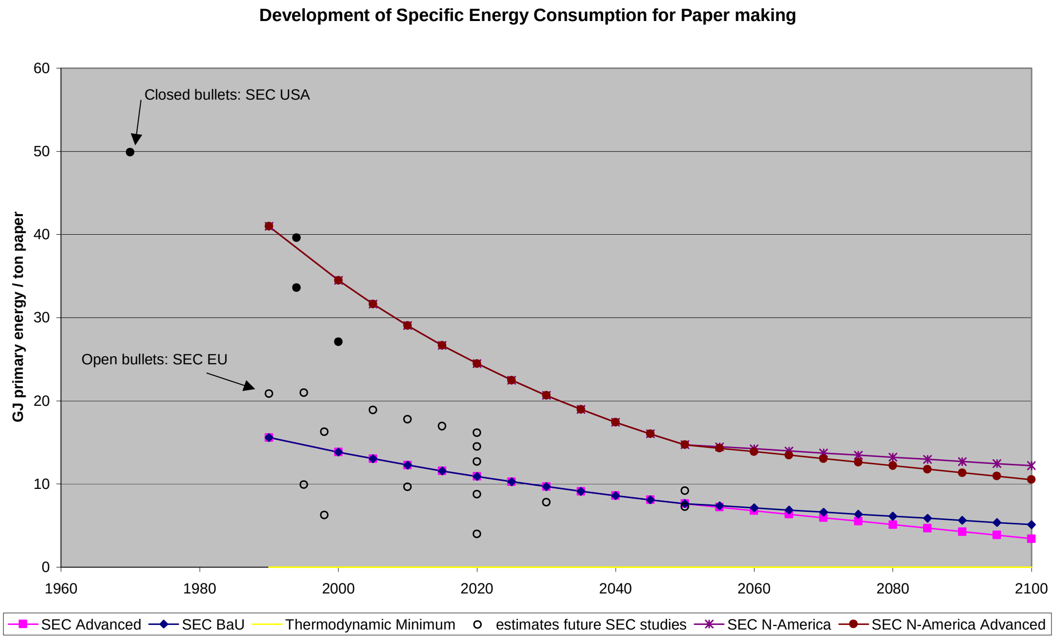
A10: Development of Specific Energy Consumption for brick production



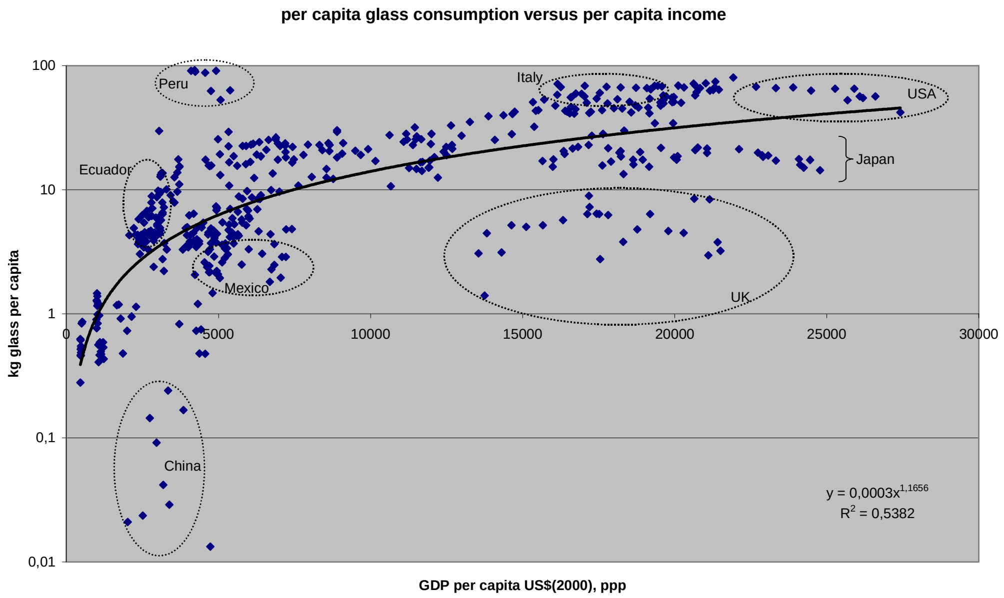
A11: Per capita fertilizer consumption versus wealth



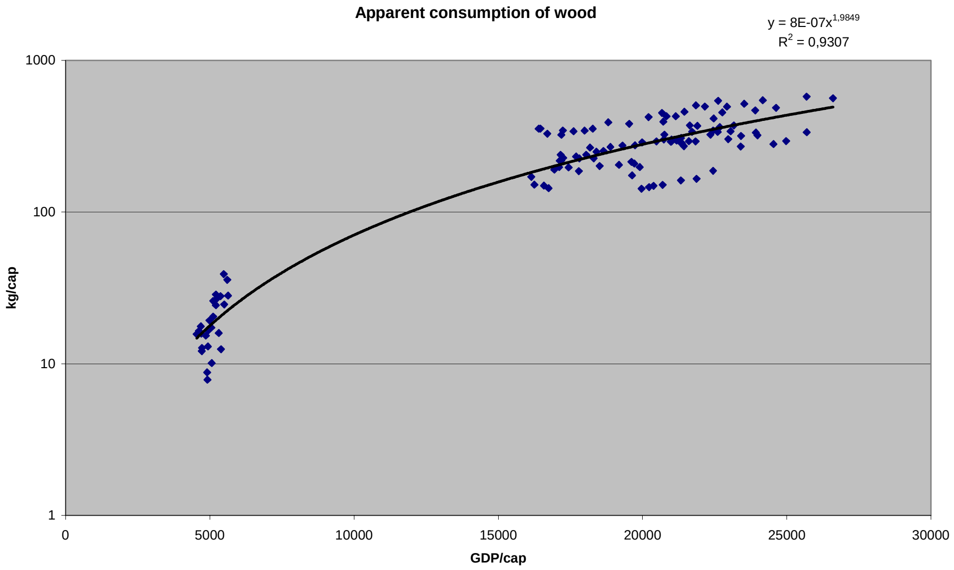
A12: Per capita polymer consumption versus wealth



A13: Development of Specific Energy Consumption for paper production



A14: Per capita glass consumption versus wealth



A15: Per capita sawnwood consumption versus wealth

Application of bulk materials by type of end-use: Paper, aluminium, glass and plastics