Chapter #

A STEP-WISE GUIDE FOR ENERGY ANALYSIS

How to calculate the primary energy requirements of households?

Kees Vringer[1], Kornelis Blok[2] and Barend van Engelenburg[3]

[1] Netherlands Environmental Assessment Agency (MNP), P.O. Box 303, 3720 AH Bilthoven, The Netherlands; [2] Utrecht University, Copernicus Institute for Sustainable Development and Innovation, Heidelberglaan 8, 3584 CS Utrecht, The Netherlands; [3] Current affiliation: Ministry of Housing, Spatial Planning and the Environment (Directorate Climate Change and Industry) , The Hague, The Netherlands

Abstract:

We need a fast and accurate method for analysing the energy requirement of consumption patterns that are inherent to many individual consumption categories. Here, we present and discuss a hybrid method of input-output analysis and process analysis to establish the energy requirement for the various consumption categories. This hybrid method for energy analysis is suitable for rapidly and accurately calculating the direct and indirect energy requirement associated with the purchase and use of large numbers of consumption categories. The method detects differences between consumption categories, even if they are produced by the same economic sector. For individual products, of which the price level deviates from the mean price, the use of input–output analysis for parts of the calculations can cause errors. However, on average, the calculated energy requirement will be correct. The error margins for individual products can be reduced by using more process data, but more effort will be needed to make the analysis.

Key words: tiered hybrid energy analysis; product energy requirement, domestic energy requirement; household consumption pattern.

1. INTRODUCTION

Not only activities of humans in households require energy, occurring in the form of natural gas, coal, petrol and electricity (direct energy requirement), but other consumption goods and services also require energy for their production, transport and trade (indirect energy requirement). In many cases a method is needed to determine the energy requirement associated with consumption patterns that is quick and fairly accurate with respect to the individual consumption categories. In other words, the method should be accurate enough to detect possible differences between the consumption categories (not between individual product variants or brands within a consumption category).

This chapter starts off by briefly discussing two existing methods for analysing the energy requirement of consumption categories, i.e. process analysis and input-output analysis. This is followed by a proposal for creating a tiered hybrid (see Suh et al., 2004) from these two methods to analyse the energy requirement for the various consumption categories. The hybrid method will be illustrated using the refrigerator as an example. The chapter ends with a discussion on the suitability of this method for calculating the total energy requirement of household consumption.

2. DETERMINING THE ENERGY REQUIREMENT OF CONSUMER GOODS

The analysis of the required energy for the whole life cycle of products had been widely practised since the early 1970s. The methods originally developed for life cycle energy analysis have been much further developed and refined in environmental Life Cycle Analysis (LCA). Even ISO made standards apply to LCA analyses (see e.g. ISO 14040, 1997). However, in contrast to LCA, the focus in this chapter will not be on environmental impacts. As in the original life cycle energy analysis, the focus will be on energy use, which is an important determinant for a variety of environmental impacts. The two basic methods for calculating the energy requirement for the life cycle of a consumer good[1], (I) input–output analysis and (II) process analysis, will be described in this section.

In *input–output* analysis the energy requirement is determined using an economic-statistical approach. The transactions between the various sectors of an economy are collected in an input–output matrix (Leontief, 1966). For

[1] The phrase 'consumer goods' is not only used for material goods but also for services purchased by consumers.

each combination of two sectors, the input–output matrix contains, in monetary terms, the supply from one sector to the other sector. A certain direct energy requirement can be attributed to each sector in the input–output matrix, for instance, on the basis of energy statistics. Subsequently, by applying several mathematical operations to the matrix, one can calculate the energy requirement associated with the delivery of the final goods to consumers. The use of input–output analysis for this aim was described and applied by Bullard and Herendeen (1975) and Wright (1974).

We can easily calculate the energy requirement of a complete life cycle from a consumer good through an input-output analysis. The method, however, is not very accurate because no distinction can be made between different products produced in the same sector, e.g. cut flowers and cherries are both produced in the same sector, i.e. horticulture. Input–output analysis implicitly assumes a sector in the input–output table to be homogeneous. In reality, a range of products is produced in one sector; some products may be relatively energy-intensive (cut flowers) and others not very energy-intensive (cherries). The input–output approach ignores these differences.

The second approach is *process analysis*, Process analysis for a certain product starts with a definition of the *life cycle*, in which all the activities required for producing, transporting, using and disposing of a product are listed. This means that an inventory has to be made of the feedstock and intermediate products and the processes involved in the production of each feedstock. Subsequently, each process occurring in the life cycle is analysed to calculate its direct energy requirement. An initial extended description of the method was given at an IFIAS meeting in 1975 (IFIAS, 1978). In the years following, this method was developed further and applied widely (Boustead and Hancock, 1979). Process analysis is more accurate than input–output analysis. However, typical life cycle analysis methods based on process analysis are very data-intensive and therefore also labour-intensive. Another problem is that in many cases not all data required for a process analysis are available.

A hybrid approach, already suggested by Bullard et al. (1978), combines the best elements of the two methods discussed before. On the basis of this proposal we developed a concrete calculation method (first published in 1994, see Van Engelenburg et al. (1994)). Nowadays, there is a growing interest in hybrid methods, both for energy analysis and for environmental LCA. Suh et al. (2004) puts the hybrid approaches into three groups, namely, tiered hybrid analysis, input-output based analysis and integrated hybrid analysis. In a tiered hybrid analysis the life cycle is split into two parts: major processes and so-called remaining processes. The major processes are those that will most probably make an important contribution to the energy requirement of the product. The process analysis approach is used for the main processes, while the input–output analysis approach is used for the remaining processes. In the input-output based hybrid analysis, important input-output sectors are further disaggregated if more detailed sectoral monetary data are available. In integrated hybrid analysis the process-based system is represented in a technology matrix by physical units per operation time of each process, while the input-output-based system is represented by monetary units. Detailed unit process level information in physical quantities is fully incorporated into the input-output model. In this taxonomy, the approach used in this thesis can be considered as a tiered hybrid. The hybrid method will be described in section 3.

3. THE HYBRID METHOD FOR ENERGY ANALYSIS WITH THE DOMESTIC REFRIGERATOR AS AN EXAMPLE

In this hybrid method for energy analysis, we calculate the primary energy requirement of a consumer good in ten steps. In the first step a flow chart of the life cycle has to be constructed, while in steps 2 and 3, a mass balance and a financial balance of the product are determined. In steps 4 to 10, numerical values are attributed to the energy requirements of the various activities in the life cycle. Finally, the various contributions made by the activities to the energy requirement are added up. The hybrid method for energy analysis is described below and illustrated by applying it to the production and use of a domestic refrigerator. For an extended description see Van Engelenburg et al. (1991; 1994).

Note that all megajoules (MJ), mentioned in this chapter refer to primary megajoules. All monetary units are converted from Dutch guilders (Dfl.,1990) to Euros. One Dfl. is about 0.45 Euro. In April 2005 one Euro (€) was about equivalent to 1.28 dollar (US$).

3.1 The first step: construction of a flow chart

The first step is to make a flow chart of the life cycle for the consumer good concerned. The flow chart should include all the activities that will probably make an important contribution to the energy requirement: i.e. production, trade and transport, consumption and waste disposal. In elaborating the flow chart one also has to select the so-called **basic materials**. These play an important role in the energy requirement connected with the complete life cycle of the product. The energy requirement for the basic materials is determined using process analysis.

In addition to the basic materials, other inputs are required for the production of the consumer good, e.g. materials with an expected small energy impact, some final processing of basic materials and services to the production. These inputs are called **residual goods**. The energy required for residual goods is determined using an input–output analysis. The energy requirement of **capital goods**, such as production equipment or an office building, is relatively small, and much effort will be needed to establish the energy requirement using process analysis. For this reason, the energy requirement for capital goods is established with an input–output analysis and considered separately.

In this first step, a number of choices has to be made. One can achieve greater accuracy by making a more detailed flow chart and selecting an increased number of basic materials; however, this also increases the amount of work involved. See Figure #1 for an example of the elements in a flow chart showing a life cycle.

The life cycle of the domestic refrigerator starts with the assembly of the refrigerator in the factory (industry sector). In the next phase, the refrigerator will be delivered to the consumer (trade sector). The refrigerator will then be disposed after use. Part of the waste will be disposed of and the remainder recycled. The refrigerator is produced in the electrical engineering industry. A standard domestic refrigerator with a capacity of 140 litres and a lifetime of 15 years is chosen as the functional unit.

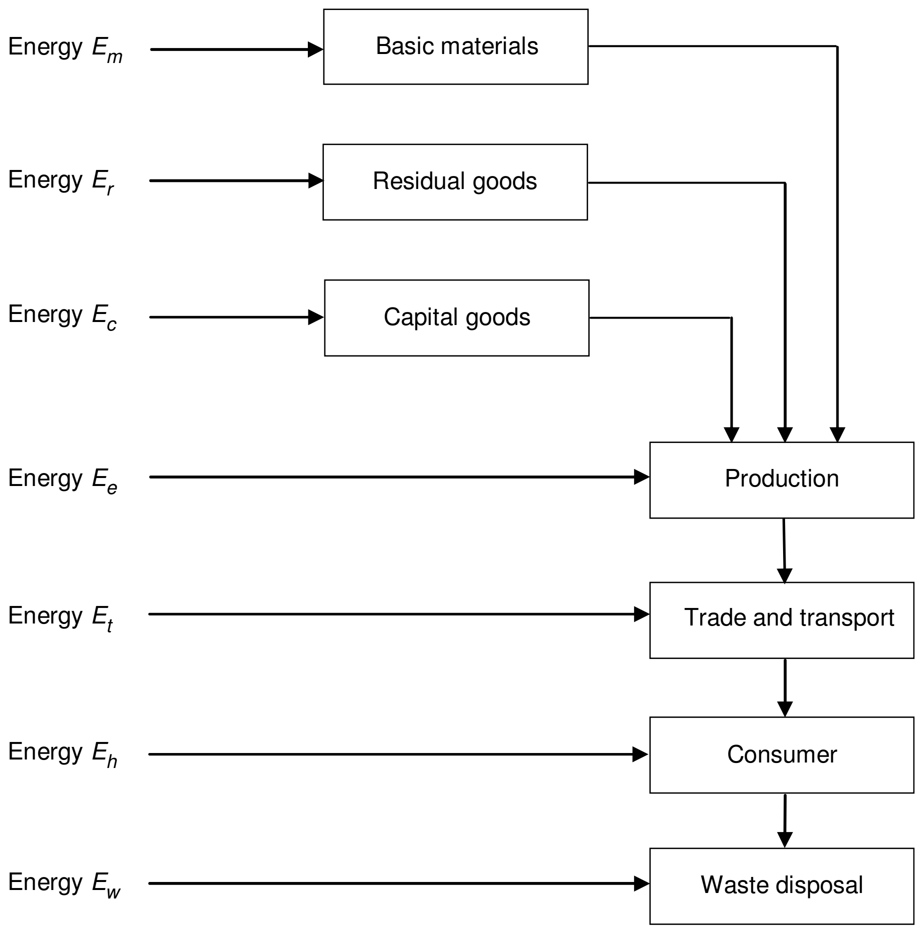

Figure #1. Example of the elements requiring energy in a flow chart showing a life cycle.

The basic materials used for the refrigerator are steel (compressor, outside wall, etc.), polyethylene (inside wall), polyurethane (insulation), aluminium (evaporator) and copper (wiring). The packaging for the refrigerator consists of a cardboard box, plastic protection materials and a single-use wooden pallet. These packaging materials are also added to the basic materials (Philips, 1989). Figure #2 shows the flow chart for the refrigerator's life cycle.

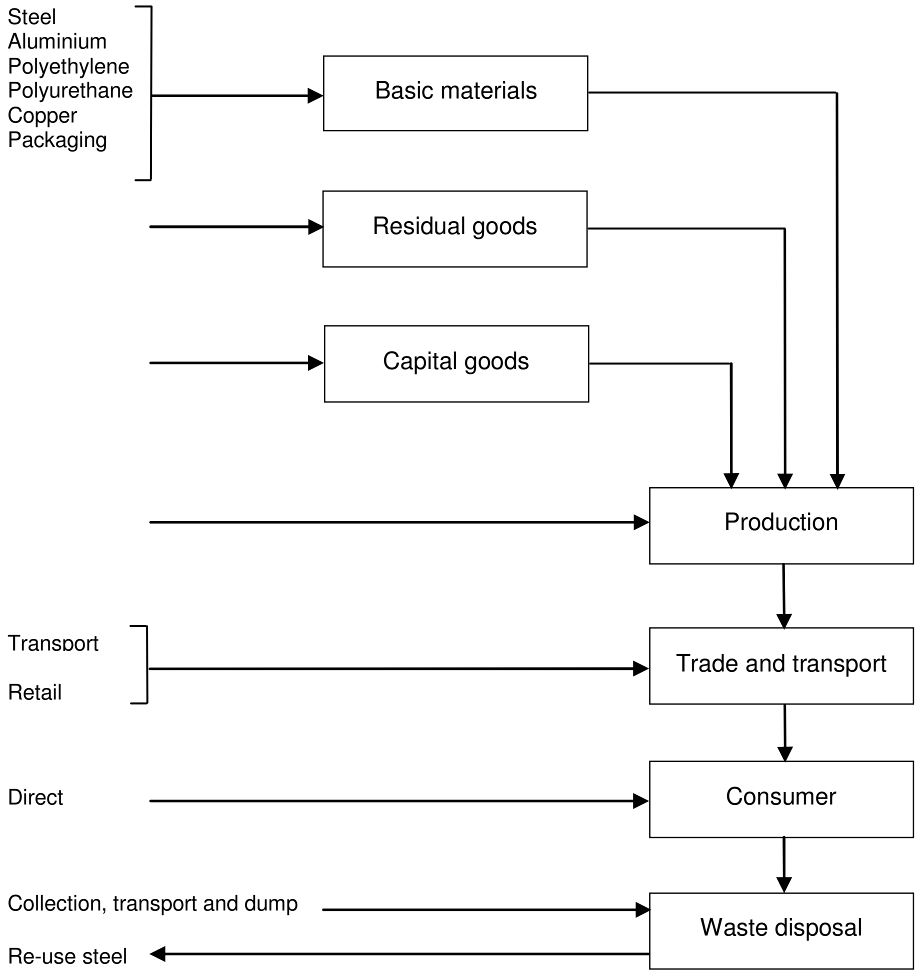

Figure #2. Flow chart of a refrigerator's life cycle.

3.2 The second step: the mass balance

With regard to the basic materials selected, a mass balance is first compiled for the life cycle determined in the first step. In many cases the composition of the product allows us to make a fairly accurate estimate of the total basic materials used in the life cycle. If there is a considerable loss of material during production, this loss should be taken into account too. Special attention should be paid to packaging materials.

The total weight, excluding packaging, of the one-door refrigerator chosen is about 35 kg (Philips, 1989) and the refrigerator consists of the basic materials listed in Table #2 (Jacobs, 1991; Willink, 1991).

3.3 The third step: the financial balance

The costs of all the activities in the life cycle are defined in this step. The retail price of the product must be broken down into the following components:

- trade margin (including taxes),
- costs of the basic materials purchased by the manufacturer,
- costs of the direct energy requirement of the product manufacture,
- depreciation incurred by the manufacturer,
- added value (excluding depreciation) realised by the manufacturer and
- purchase of residual goods by the manufacturer.

In most cases there are no specific figures available from the manufacturers or the trade sector involved in producing and selling a specific product, so approximations have to be made. In the approximation made here, one first of all has to determine an average product price, for example, on the basis of information provided by retailers, retailers' associations or consumer associations. The costs of basic materials are assessed on the basis of the mass balance, combined with the specific costs for the various materials, and expressed as costs per kg. From national statistical data, such as production statistics and input–output tables, one can obtain sector-averaged values for the trade margin, depreciation and value added. The remaining costs are attributed to the closing entry: the so-called *residual goods*. The consumer price of the refrigerator was about 360 Euro, incl. 18.5% VAT (Philips, 1989). This price can be broken down as shown in Table #1.

Table #1 *Breakdown of the price of a refrigerator (excl. VAT).*

Cost component	**Costs* per refrigerator** (€)
Basic materials in costs per kg (steel 0.5, aluminium 1.4, polyethylene 0.7, polyurethane 3.6, copper 1.6, cardboard 0.9, polystyrene 1 and wood 0.4)	43
Energy requirement for manufacturing a refrigerator (see step 5)	1.2
Depreciation	8.2
Value added	67
Retail margin	130
Residual goods	57

* Most of the costs for basic materials are derived from national statistics data for 1986 or 1990, collected by Wilting (1992).

3.4 The fourth step: energy requirement for producing the basic materials (E_m)

The cumulative energy E_m required for producing the basic materials is calculated by adding up the gross energy requirements for all basic materials. The energy requirement relating to the use of basic materials for the refrigerator is shown in Table #2.

Table #1. Energy requirement for the production of basic materials (Van Heijningen et al., 1992/1993, Fraanje, 1990 and Krekel van der Woerd Wouterse, 1983).

Basic material	**Mass** (kg)	**GER** (MJ/kg)	**Primary energy requirement** (MJ)
Steel	25.0	23.4	585
Aluminium	0.5	198	99
Polyethylene	2.5	71	178
Polyurethane	6.0	190	1140
Copper	0.5	100	50
Cardboard (packaging)	1.5	26	39
Plastic (packaging)	0.5	70	35
Wood (packaging)	10.0	33	330
Total	**46.5**		**2456**

3.5 The fifth step: energy requirement of the residual goods (E_r)

In addition to basic materials, various other goods or modifications, called residual goods, are used by the manufacturing sector. The cost of residual goods was calculated in step 3. The energy intensity of residual goods was calculated with an input–output analysis. However, this approach will have to be modified, since the basic materials, of which the energy requirements have already been taken into account, have to be omitted from the analysis. This modification is carried out by 'ignoring' the contribution made to the energy requirements by the sectors producing the selected basic materials, i.e. by setting the direct energy requirement of these sectors at zero (see Wilting (1996) for an extended description).

In the second step, the cost price of the residual goods for the refrigerator was calculated at 57 Euro. The basic materials used in the production sector come from the:

- timber industry, including furniture,
- paper and paper-product industry,
- chemical industry and
- base metal industry.

According to our hybrid approach, the energy requirements of these sectors will be set at zero. The energy intensity for the residual goods can be calculated using this assumption. Energy intensity is calculated at 5.7 MJ/€, resulting in an energy requirement for the residual goods of 323 MJ per refrigerator.

3.6 The sixth step: direct energy requirement for manufacturing the product (E_e)

This step determines the direct energy requirement of the production process. This energy requirement can be calculated using process analysis. Since, in most cases, no process data are available, we can use the average energy intensity derived from national statistics data for the production sector in which the product was manufactured.

The direct energy requirement for the production of a refrigerator could not be calculated through process analysis because of lack of data. We therefore used the average energy requirement of the sector as derived from National Statistics (CBS). The direct energy intensity (= energy requirement per unit production value) in the electrical engineering industry is 2 MJ/€

(CBS, 1991). Since the production price was € 176, the direct energy requirement per refrigerator is calculated at 351 MJ.

3.7 The seventh step: energy requirement for the manufacture of capital goods (E_c)

The input–output tables published by national statistics offices generally include the investments (purchase of capital goods required to produce consumer goods, e.g. buildings) in the final demand category and not in the internal supplies of the various sectors delivering to each other. Consequently, the investments in buildings and other capital goods are not included in the energy requirement calculated for consumer goods by means of input–output analysis. To correct for this deficiency we have to calculate the demand that the production of capital goods makes on primary energy carriers. The energy intensity of investments is calculated by applying input–output analysis, as described by Bullard and Herendeen (1975), and results in one figure, 9 MJ/€, for all sectors (Wilting, 1992). The depreciation of the capital goods in the manufacturing industry per refrigerator is 8.1 Euro. The associated energy requirement is calculated at 73 MJ per refrigerator.

3.8 The eighth step: energy requirement for the transport and trade sector (E_t)

Transport and trade form part of most life cycles. The product is usually transported from the factory (sometimes via the wholesale trade) to the retailer and from the retailer to the household. The weight of the product (i.e. the load) and the distance over which the product has to be transported must be specified for each mode of transport (e.g. train, lorry, ship). Energy is also used by the wholesale, distributive and retail trades.

The refrigerator is transported from factory to retailer and from retailer to household. The distance from the factory to the retailer is estimated at 500 km (the refrigerator is produced in Germany and sold in the Netherlands). This route, covered by lorry/truck, requires 2.5 MJ/ton-km (Boustead and Hancock, 1979 and BGC, 1991). The distance from the retailer to household, estimated at 15 km, is made by a delivery van and requires 8.5 MJ/ton-km (Boustead and Hancock, 1979 and BGC, 1991). The energy requirement for transport of the refrigerator (including packaging) can now be calculated at 65 MJ.

The trade sector also uses energy by supplying the product or service to the household. The value added from the trade sector was calculated in step 3. The value added (CBS, 1992a), multiplied by the energy intensity of the trade sector results in the energy requirement for the trade sector, which, per refrigerator, is 130 (€) x 4.6 (MJ/€) = 600 MJ.

3.9 The ninth step: direct energy requirement in the consumption phase (E_h)

Some products, such as cars, refrigerators and cookers, require energy during the consumption phase. With an ambient temperature of 18 °C, the refrigerator uses approximately 0.5 kWh electricity in 24 hours or 180 kWh per year (Philips, 1989). This annual requirement is equal to 1854 MJ of primary energy. The lifetime of a refrigerator is assumed to be 15 years, so the total direct energy requirement of the refrigerator is 27.8 GJ of primary energy.

3.10 The tenth step: energy requirement for waste disposal (E_w)

The life cycle ought to take into account the waste disposal associated with the consumer good. Waste disposal can consume energy, for instance, in connection with collection and transport. But disposal can also yield energy if the materials are recycled or incinerated.

The energy needed for collection and transport of the refrigerator amounts to about 14 MJ primary energy (DHV, 1985). The steel of the refrigerator will be re-used, while the remainder will be dumped, with 22 kg waste requiring 2.0 MJ (DHV, 1985). The re-use of 25 kg steel saves 400 MJ (Wilting, 1992). So the waste disposal for the refrigerator results in an energy gain of 384 MJ per refrigerator.

3.11 The final step: adding up the energy requirements

Finally, the various contributions made to the energy requirement by feedstock supply, manufacturing, use and disposal of a product can be added up. We have now calculated the total energy requirement of the product and its use. If the fraction of the residual goods contained in the cumulative energy requirement is decided to be too large, a more detailed life cycle should be constructed and the whole analysis for the modified part of the life cycle repeated. Mind that a threshold depends on the purpose of the analysis.

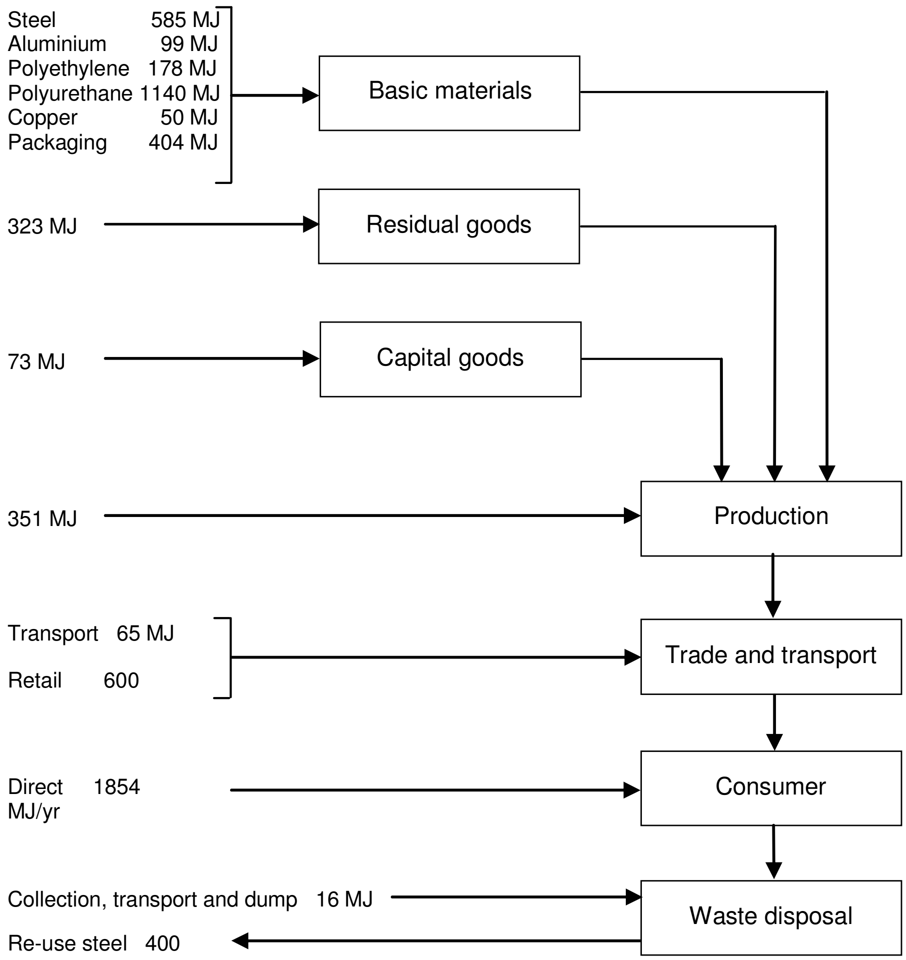

Figure #3. Flow chart of the life cycle of the refrigerator, together with the energy requirements in the various steps.

Figure #3 shows the results of the preceding steps, inserted into the flow chart of the life cycle for the refrigerator, as shown in Figure #2. The cumulative energy requirement for the production, consumption and disposal of one refrigerator is calculated at 31 GJ over its entire lifetime of 15 years. The figures show the indirect fraction for the refrigerator to be about 10%. The energy intensity of a consumer good is defined as the total energy requirement divided by the purchase costs of the product. The energy intensity of the refrigerator is 9.5 MJ/€ when only the equipment itself is taken into account and 51 MJ/€ when the direct electricity requirement in the household is also included.

4. THE SUITABILITY OF THE HYBRID METHOD FOR DETERMINING THE ENERGY REQUIREMENT OF CONSUMPTION PATTERNS

As previously stated, if the primary energy requirement of consumption patterns is to be analysed, the energy analysis method has to be rapid. The energy analysis method must also be accurate enough to detect the differences between consumption categories and consumption patterns. Below, we discuss the calculation speed and the accuracy of the hybrid method in analysing the energy requirement of consumer goods.

4.1 Making a quick energy analysis of consumer goods

The hybrid method for energy analysis described above may look very labour-intensive due to the large amount of input data required. But it should be pointed out that these input data can be standardised to a large extent and thus be used for many consumer goods. The hybrid method for energy analysis, along with databases containing a standardised input data set for the Netherlands, have been incorporated into a computer program called the Energy Analysis Program (EAP) (Wilting, 1992; 1999 and Benders et al., 2001). The energy requirement and energy intensity of large numbers of consumer goods can be calculated relatively quickly with the EAP.

A lot of data are available in the EAP program. Only limited additional data of the product analysed (e.g. weight, price, country of production and most important materials) are required for the analysis. The rest of the required data can be estimated quite easily, e.g. data from the production and trade sectors, transportation distances and kinds of waste disposal. In this way all 350 consumption categories from CBS (1992b) (covering the complete Dutch consumption package) were analysed in about two person-years (see De Paauw and Perrels (1993), Kok et al. (1993), Vringer and Blok (1993) and Vringer et al. (1993)). This comes to only about 10 hours per consumption category, which makes the hybrid method for energy analysis applicable to calculating the energy requirement of consumer goods without the classic data problems of process analysis.

4.2 Accuracy of the hybrid method for determining the energy requirement of consumer goods

The highest inaccuracy in the hybrid method for energy analysis in calculating the energy requirement of consumer goods will probably be caused by the use of input–output analysis to calculate the energy requirement for producing residual goods and the energy requirement for trade. However, the uncertainties that stem from the use of input–output analysis for residual goods can be partly avoided by minimising the use of this analysis through incorporation of sufficient process data on the basic materials.

4.3 Accuracy in the energy requirement of trade

The energy requirement for retail trade is an example of a component of the life cycle of a product, where the energy requirement is calculated by using energy intensities on a monetary basis. For some products, the share of retail trade in the total calculated indirect energy requirement is more than 25% (see, for example, Vringer et al. (1993) and De Paauw and Perrels (1993)). The energy requirement for retail trade is assigned on a financial basis. This means that if the price of the product doubles, the energy requirement allocated to retail trade also doubles. This 'financial' way of assigning the energy requirement to retail trade may result in an overestimation of the retail trade energy requirement for more expensive products and an underestimation of cheaper products of the same kind. The retail trade energy requirement can also be assigned on a physical basis. In this case the energy requirement is assigned per item, per kilogram or cubic metre of product and is not affected by the price of the product. This assignment or ‘physical’ accounting method may result in an underestimation of the energy requirement of the retail trade for the more expensive products, since fewer products per square metre of retail space will have to be sold to realise the same turnover per square metre.

Vringer and Blok (1996) have provided an estimation of the error, made by assigning the energy requirement of the retail trade, either on a financial or physical basis. They made a detailed energy analysis, based on the annual sales per square metre floor, of two retail branches: clothing shops and shoe shops. Compared with this alternative detailed accounting method of the energy requirement of the retail trade, the *financial* accounting method indicates an overestimation for expensive clothes and shoes (4 to 14%), and an underestimation for cheaper clothes and shoes (-6%). The calculated energy requirement for clothes and shoes using the *physical* accounting method is about 2 to 10% too high for the low-price level shops and 2 to

17% too low for the high-price level shops. It is quite conceivable that more expensive shops will require relatively more energy for lighting and heating per square metre than cheaper shops. This means that the energy requirement of the retail trade will be higher for more expensive products and lower for cheaper products of the same kind than estimated here.

Vringer and Blok (1996) concluded that both financial and physical accounting methods for the energy requirement of retail trade would cause errors for products with a price level deviating from the average price. For individual purchases of clothes and shoes, the systematic error may be about 5 to 15% of the total indirect energy requirement. However, for the average of all shoes or all clothes, the energy requirement would be about right.

5. CONCLUSIONS

The hybrid method for energy analysis as proposed by Van Engelenburg et al. (1994) and worked out by Wilting (1992) and Wilting et al. (1999) can be concluded as being suitable for rapidly calculating the direct and indirect energy requirement associated with the purchase and use of large numbers of consumer goods. The hybrid method detects differences between consumption categories, even if they are produced by the same economic sector. The use of input–output analysis, based on a financial accounting method, for parts of the calculations can cause deviations for individual products, with a price level deviating from the average price. However, on average, the calculated energy requirement will be correct. Although the error margins for individual products can be reduced by using more process data, more effort will be needed to make an analysis.

6. REFERENCES

Benders, R.M.J., H.C. Wilting, K.J. Kramer and H.C. Moll, 2001, Description and application of the EAP computer program for calculating life-cycle energy use and greenhouse gas emissions of household consumption items, Int. J. Environment and Pollution, **15** (2), pp. 171-182.

BGC, Bureau Goudappel Coffeng, 1991, Energieverbruik in Verkeer en Vervoer in cijfers (Figures for the energy requirement in traffic and transport), NOVEM, Utrecht.

Boustead, I. and G.F. Hancock, 1979, Handbook of Industrial Energy Analysis, Ellis Horwood, Chichester, UK.

Bullard, C.W. and R.A. Herendeen, 1975, The energy costs of goods and services: an input/output analysis for the USA, 1963 and 1967, Energy Policy **3**, 268-278.

Bullard, C.W., P.S. Penner and D.A. Pilati, 1978, Net Energy Analysis, Handbook for Combining Process and Input-Output Analysis, Resources and Energy **1**(3), 267-313.

CBS, 1991, De Nederlandse Energiehuishouding, Jaarcijfers 1989 en 1990 (Energy Supply in the Netherlands, Annual Figures 1989 and 1990), The Hague.

CBS, 1992a, Statistisch Jaarboek 1992 (Statistical Yearbook 1992), SDU, The Hague.

CBS, 1992b, Budgetonderzoek 1990, micro bestand (Netherlands Household Expenditure Survey 1990 (computer file), Statistics Netherlands, Voorburg/Heerlen, The Netherlands.

DHV, 1985, Energiekentallen afvalverwijderingssystemen (Energy figures for waste disposal systems), Amersfoort, The Netherlands.

Engelenburg, B.C.W. van, T.F.M. van Rossum, K. Blok, W. Biesiot and H.C. Wilting, 1991, Energiegebruik en huishoudelijke consumptie - handleiding en toepassingen (Energy use and household requirement - manual and applications), Dept. of Science, Technology and Society, report no. 91032, Utrecht University and the Centre for Energy and Environmental Studies, University of Groningen, The Netherlands.

Engelenburg, B.W.C. van., Rossum, T.M.F. van Rossum, K. Vringer and K. Blok, 1994, Calculating the energy requirements of household purchases --- a practical step by step method. Energy Policy **22**(8), 648-656.

Fraanje, P., 1990, Minimalisering van milieubelasting in de woningbouw (Minimisation of the environmental impacts of house-building), Interfaculty Department of Environmental Science, University of Amsterdam, The Netherlands.

Heijningen, R.J.J. van, J.F.M. de Castro and E. Worrell, 1992, Energiekentallen in relatie tot preventie en hergebruik van afvalstromen (Gross-energy-requirement figures related to prevention and re-use of waste streams), NOVEM, Utrecht.

Heijningen, R.J.J. van, J.F.M. de Castro, E. Worrell, 1993, Meer energiekentallen in relatie tot preventie en hergebruik van afvalstromen (More Gross-energy-requirement figures related to prevention and re-use of waste streams), NOVEM, Utrecht.

IFIAS, 1978, IFIAS Workshop Report ‘Energy analysis and Economics’. Resources and Energy **1,** 151-204.

ISO 14040 (1997), Environmental management – life cycle assessment – principles and framework, International Organisation for Standarisation (ISO).

Jacobs, 1991, Personal communication, Miele Netherlands bv, Vianen, The Netherlands.

Krekel van der Woerd Wouterse, 1983, Energie en economie (Energy and Economy), Rotterdam.

Kok, R., Wilting, H.C., Biesiot, W., 1993, Energie-intensiteiten van voedingsmiddelen (The energy intensities of food). Centre for Energy and Environmental Studies, University of Groningen, The Netherlands. Report no. 59.

Leontief, W., 1966, Input-Output Economics, Oxford University Press, NY.

Paauw, K.F.B. de and A.H. Perrels, 1993, De Energie-intensiteiten van consumptiepakketten (The energy intensity of consumption packages), ECN-policy studies, Petten. Report ECN-C-93-043.

Philips, 1989, Product information. Eindhoven, The Netherlands.

Suh, Sangwon, Manfred Lentzen, Graham J. Treloar, Hiroko Hondo, Arpad Horvath, Gjalt Huppes, Olivier Jolliet, Uwe Klann, Wolfram Krewitt, Yuichi Moriguchi, Jesper Munksgaard and Gregory Norris (2004) System Boundery Selection in Life-Cycle Inventories Using Hybrid Approaches. Environmental Science & Technology **38**(3), 657-664.

Vringer, K., and K. Blok, 1993, Energie intensiteit van de woning (Energy intensities of dwellings) Department of Science, Technology and Society (NW&S), Utrecht University, The Netherlands.

Vringer, K., J. Potting and K. Blok, 1993, Energie intensiteiten van de huishoudelijke inboedel (Energy intensities of household effects). Department of Science, Technology and Society (NW&S), Utrecht University, The Netherlands.

Vringer, K., and K. Blok, 1996, Assignment of the energy requirement of retail trade to products. Utrecht University, The Netherlands (internal note).

Willink, 1991, Personal communication, Service IRE Netherlands bv, Vianen, The Netherlands.

Wilting, H.C., 1992, EAP, Energie Analyse Programma, Handleiding, (EAP, Energy Analysis Program, Manual), Centre for Energy and Environmental Studies, University of Groningen, The Netherlands.

Wilting, H.C., 1996 *An energy perspective on economic activities*. Thesis, Groningen.

Wilting, H.C., R.M.J. Benders, W. Biesiot, M. Lourerd and H.C. Moll, 1999, EAP, Energy Analysis Program, Manual version 3.0, Centre for Energy and Environment Studies, University of Groningen, The Netherlands. Report no. 98.

Wright, D.J., 1974, Goods and Services, an input-output analysis, Energy Policy (**2**) December, pp. 307-315.