

Parallels between energy efficiency in domestic appliances and environmental life cycle analysis of products

Mark Hinnells, Manchester Metropolitan University, UK

1. ABSTRACT

Legislation is changing in many countries either to encourage, or to force environmental side effects to be taken into consideration in domestic appliances. This paper discusses some of the parallels and differences in methodology of Environmental LCA and energy efficiency studies, and discusses first, the advantages and disadvantages of expanding the system boundary beyond energy consumption in use, and second, of examining net impacts rather than gross emissions. In some product categories, there may be conflicts between energy efficiency and other environmental objectives, requiring conflict resolution, and the identification of priorities. A study of a refrigerator is used as an illustration. The major impact of refrigeration appliances are emissions from energy consumption and the effects of CFCs and CFC-replacements.

2. INTRODUCTION

Legislation is changing in many countries either to encourage or to force environmental side effects to be taken into consideration in domestic appliances. Many schemes concentrate on energy consumption in use. Others use a complete Life Cycle Analysis (LCA), evaluating total environmental impact from raw material extraction, manufacture, distribution, use and disposal (to many energy analysts, however, Life Cycle Analysis means a life cycle examination of energy costs).

Legislation includes: compulsory energy labelling; mandatory minimum standards for energy efficiency; eco-labelling schemes (mostly based on LCA); and compulsory recycling of packaging, which is likely to be extended, in some form, to appliances. This paper discusses some of the parallels and differences in methodology of Environmental LCA and energy efficiency studies, and shows how each approach could learn from the methodology of the other. Energy efficiency studies have to date discussed other environmental impacts only when there is a direct relationship to energy consumption (eg water consumption in washing

Table 1. *Key impacts of a refrigerator through the life cycle*

| | Manufacture | Distribution | Use | Disposal |
|----------------------|----------------------|--------------|--|---------------------------|
| Energy use | Energy and materials | | | |
| Material consumption | | | | |
| Solid waste to land | | | | Solid waste |
| Water pollution | | | | |
| Air emissions | | | CO ₂ NO _x SO _x emissions | CFCs and CFC replacements |

Table 2. Product level intervention on energy and environment

| | Energy labels | Environmental labels | Other policies |
|-------------|-----------------|--------------------------------------|--------------------------|
| U.S. | Energy guide | Green Cross Green Seal Cal-EPA | Energy Star Standards |
| EC | Energy labels | Eco-labels | Standards? |
| Canada | | Environmental choice | |
| Scandinavia | Energy labels | Miljömarket | Standards? |
| Japan | Energy labels?? | Environmental labels | |

machines (USDOE 1990), while LCA studies of appliances concluded that energy consumption is the largest environmental impact (PA Consulting 1992).

The public policy implications of these different approaches -including information based instruments (labels); price based instruments (taxes, incentives and rebates) and product based instruments (minimum standards)- are examined elsewhere (Hinnells, 1993 forthcoming; Hinnells, 1993b). It is useful to note, however, that the barriers to recycling are similar to the barriers to energy efficiency, and include economic, regulatory and technical barriers. Several price-based and product-based tools are under consideration. Price based mechanisms include: removing existing inequalities (reduce subsidies to virgin material) and internalising external costs (increasing landfill costs, or increasing the price of virgin material, and a deposit/refund scheme to pay for recycling). Product based tools include regulatory mechanisms (forcing manufacturers to use a fraction of recycled material in products), and support for innovation (provide subsidies to research in recycling).

3. THE EXISTING LITERATURE

3.1. Energy efficiency in domestic appliances

The US National appliance Energy Conservation Act (NAECA) mandates the development of minimum standards for energy efficiency in domestic electrical appliances (eg, refrigerators and freezers (USDOE 1989); washing machines dishwashers and tumble dryers (USDOE 1990); and heating, lighting and ventilation). Minimum Standards are under development in the EC (Lebot, Szabo et al. 1991).

In developing standards, a technical analysis is made of a number of design options which can improve the efficiency of an appliance. Each design option is analysed separately to assess the change in energy consumption, and the incremental cost of the improvement. Design options are then combined. Standards are set at a level where design options are both technically feasible and economically justified (ie short payback time -less than 3 years in the US- and low life cycle cost). The models are predictive. Any change in total energy consumption depends on the characteristics of old and new appliances, the rate of new appliance purchase, and consumer choice and behaviour. The models demonstrate possible options for intervention by government to improve the characteristics of new appliances, for example (USDOE 1990; Lebot, Szabo et al. 1992):

- (a) Minimum standards based on a statistical approach (eg, removing the bottom ten percent of products from the market),

- (b) Minimum standards set at a level which is economically justified (ie, measures with a pay-back to the consumer of less than three years),
- (c) Minimum standards based on equivalent Life Cycle Cost (ie, which combination of features in a product with the same life cycle cost over the life of a product, but with the least energy cost).

Recent studies have considered the potential for energy conservation from office equipment (especially computers and photocopiers). A similar approach has been used to reduce water consumption in certain household products such as toilets and showerheads .

3.2. Material flow studies, source reduction and recycling

Some studies have examined the increase in material flows to waste and strategies for reduction. Some of the work is focussed on policy instruments (US EPA 1977; US OTA 1989), and some at particular product areas including appliances (Whalley 1982), motor vehicles (Williams 1991), disposable and reusable diapers (Franklin Associates Ltd 1990; Lehrburger 1988; Little 1990; Nordman 1991), and electronic equipment (Roy 1991). Other studies have examined the flow of particularly toxic materials to the environment, such as mercury in fluorescent lamps, or Chloro-Fluoro-Carbons (CFCs) in refrigerators (Fischer, Hughes et al. 1991).

The German Government has introduced new laws to enforce recycling packaging (the 'Töpfer Decree', after Claus Töpfer, German Environment Minister). Compulsory recycling will be extended in 1996 to motor vehicles, and domestic and electrical appliances at the end of their useful life.

3.3. Life cycle analysis

Attempts to examine several environmental impacts of products or systems began during the 1970s. A number of titles were given to these studies including Resource and Environmental Profile Analysis, and Material and Energy Balances. Several studies on both sides of the Atlantic examined the energy and resources conflicts in beverage container systems, including reusable glass bottles and disposable plastic bottles (Boustead 1974; US EPA 1974).

The predominant focus for the last decade has been energy. However, increasingly there has been a recognition of the environment as a system (encouraged both by the threat of climate change, and by the discovery of a hole in the ozone layer). This has led to a resurgence of interest in a 'systems' approach to environmental impact studies. Some LCA studies, particularly those undertaken by private consultants on behalf of an industry or product have been criticised on their methodology. Several handbooks on LCA methodology have been published very recently (SETAC 1992; SETAC 1991; Battelle and Franklin Associates (Draft)). Some attempt at cross-environmental impact study has been used as the basis for several environmental labelling schemes: the Canadian 'Environmental Choice' Scheme; the 'Miljömarkt' began in 1992 in the Nordic countries; and an EC scheme the 'Eco-Label' will be introduced in September 1993. The US and Japan also have some form of environmental labelling.

The value of a broad-based environmental assessment is in prioritising environmental problems and identifying conflicts between different impacts which single issue studies do not address: for example, the aim of one study was to identify:

those aspects of the life cycle of a washing machine which have the most significant environmental impacts. Recognising that data to enable the evaluation of environmental impacts are not always available, the focus of the analysis was therefore to obtain some estimate of environmental impact of the complete life cycle, however approximate it may be in some areas, rather than to make a precise evaluation. By having a complete model available, it is then possible, by sensitivity analysis, to explore the impact of some of the assumptions made and identify those areas where more information is needed, and hence focus research efforts. (PA Consulting 1992, 9)

An LCA study of washing machines drawn up for the EC Eco-Labeling Scheme (PA Consulting 1992) concludes that over 90% of environmental impact of a washing machine is from energy, water and detergent consumption during use (see (b) below); second, that energy consumption is proportional to water consumption since most of the energy is used in heating the water; and third that:

If the best practice were used in production, distribution and disposal... this would represent only about 1% of environmental impact. Best practices in the use of the product [energy, water and detergent consumption] could reduce environmental impact by 25%. (PA Consulting 1992, 37)

There are many issues in developing the methodology of cross-impact studies. Two key issues are:

- (a) **Definition of the system boundary:** Studies of waste problems have pointed out that fluorescent lamps contain mercury and radioactive elements, but studies of the *whole* life cycle suggest that, on an energy service basis (ie equivalent light output in lumenhours), fluorescent lighting emit lower levels of mercury and radioactivity throughout the life cycle than incandescent lamps, because of the saved emissions from power stations through reduced energy consumption (Muis, Posthumus et al. 1990, and Gydesen and Maimann 1991).
- (b) **Aggregating data:** in order to assess impacts of several emissions, the quantities of the constituent elements are frequently totalled into *effects*, such as total contribution to global warming; total acidification impact; Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) Critical air volume; and critical water volume. Effects are generally a sum of the mass of each pollutant multiplied by a factor to account for the relative impact of that pollutant. The 'factor' can be open

Table 3. Design options for minimum standards for energy efficiency in refrigerators.

| | Increase in product cost | Energy saving | Cost of energy saved | Simple payback period |
|--|--------------------------|---------------|----------------------|-----------------------|
| | ECU | kWh/p.a. | ECU/p.a. | Years |
| 1 Increased door insulation | 4 | 28,7 | 3,4 | 1,2 |
| 2 Increased cabinet insulation | 14 | 51,6 | 6,2 | 2,3 |
| 3 Double evaporator surface | - | - | - | - |
| 4 Double condenser surface | 26 | 16,1 | 1,9 | 13,7 |
| 5 Double evaporator heat capacity | 5 | 2,9 | 0,3 | 16,7 |
| 6 Double condenser heat capacity | 6 | 9,9 | 1,2 | 5 |
| 7 Optimized compressor | 9 | 36,2 | 4,3 | 2,1 |
| 8 Decreased door leakage | 1 | 5,4 | 0,6 | 1,7 |
| 9 Replace foam ins. w/ vacuum panel ins. | - | 184 | 22,1 | - |

Sample refrigerator with 1-star fast freeze compartment, assuming an average EC electricity price of ,12 ECU/kWh.

to much discussion, particularly critical air volume and critical water volume which use national emissions limits (in mg/litre), which are based on political as well as scientific factors.

PA used a critical air volume and critical water volume approach in their study of washing machines to aggregate data (above). Aggregation based on total contribution to global warming is now used for refrigerators.

4. A CASE STUDY THE ENVIRONMENTAL IMPACT OF REFRIGERATORS

The development of minimum standards for refrigerators in the EC included an examination of the wider environmental impact of refrigerators at key stages of the lifecycle (Hinnells 1993). Options considered by GEA are shown in table 3: they are simple design parameters. In addition, an LCA study is currently under development for refrigerators and freezers, with the aim of establishing criteria for an EC Eco-Label (ENEA 1992). The study identifies options for CFC substitution and recycling (table 4). This present study is in no way a complete environmental Life Cycle Analysis (LCA) of Refrigerators and Freezers: however, the impacts of key stages of the lifecycle have been examined.

4.1. In use

Emissions from power generation are shown to be 85% + of the Total Equivalent Warming Implications (TEWI) of a refrigerator throughout its life cycle (including the impact of CFCs and CFC-replacements), and to comprise the greatest potential for reducing environmental impacts of domestic refrigeration appliances.

4.2. Disposal

On disposal, (unless it is deliberately collected) all the remaining refrigerant is released when the refrigerant circuit is broken. There is almost complete release of foaming agent contained if the appliance is shredded, for example for steel reclamation. If the appliance is disposed of without breaking up, for example burying in landfill, about 1% of foaming agent is leaked per annum. The disposal of a refrigerator impacts solid waste and water pollution. Whalley suggests the average Refrigerator disposed of in the UK contains 21 kg mild steel, 2.8 kg of other metals such as stainless steel aluminium and copper, 10.5 kg plastics and rubber, and 0.7 kg of inerts such as glass (Whalley 1982).

4.3. Total equivalent warming impact of refrigerators

The main impact of a refrigerator is in the contribution to global warming both from emissions from power generation and from CFCs and CFC-replacements. In addition, chlorine and bromine containing compounds have been strongly implicated in ozone depletion. However, it has been hypothesised that ozone depletion

Table 4. Design options for study for an EC Eco-label

| | Refrigerator fluid | Foaming agent | Disposal |
|----|------------------------------|---------------|-------------------------------|
| A1 | CFC | CFC | Dumping |
| A2 | CFC | CFC | Recovery of CFC |
| A3 | CFC | CFC | Recovery of CFC and materials |
| B1 | HFC + 10% energy consumption | CFC | Recovery of HFC |
| B2 | HFC no increase in energy | CFC | Recovery of HFC |
| B3 | HFC no increase in energy | HCFC | Recovery of HFC |

has an indirect negative warming effect, which would offset 80% of their direct greenhouse effect (Wigley and Raper 1992). Thus CFC-replacements with a lower ozone depleting potential may turn out to have a more severe net (ie direct and indirect) greenhouse effect.

A typical *existing* EC refrigerator contains (Fischer, Hughes et al. 1991)¹

- (1)
 - 140g of CFC-12 refrigerant
(CFC-12 has a direct GWP of 7100 kg CO₂ per kg of CFC-12, 80% offset by ODP)
 - 3.36 kg of foam insulation, 202g of CFC11 in the insulation...
(CFC-11 has a direct global warming potential of 3400 kg CO₂ per kg CFC-11, 80% offset by ODP)
 - it consumes an average of 485 kWh of electricity per year for 15 years...
(the current energy generating mix in Europe results in 513g of CO₂ per kWh delivered.)

The equivalent CO₂ Emissions are therefore:

$$\begin{aligned}
 &= (0.14 \cdot 7100 \cdot 0.2) + (0.202 \cdot 3400 \cdot 0.2) + (485 \cdot 15 \cdot 0.513) \\
 &= 198.80 + 137.360 + 3732.08 \\
 &= 4068.24 \text{ kg CO}_2
 \end{aligned}$$

- (2) A 320 l combined fridge freezer uses 156g CFC-12 and 402g CFC-11, and total power consumption of 5677 kWh (ENEA 1992 Case A1):

$$\begin{aligned}
 &= (0.156 \cdot 7100 \cdot 0.2) + (0.402 \cdot 3400 \cdot 0.2) + (5677 \cdot 0.513) \\
 &= 221.520 + 273.360 + 2912.301 \\
 &= 3407.181 \text{ kg CO}_2
 \end{aligned}$$

The *order of magnitude* net warming impact of example (1) therefore consists of 5% from the refrigerant, 3% from insulation, and 92% from CO₂ from energy consumption. CFCs account for about 330 Kg CO₂ Equivalent. Example (2) gives a net warming impact of 6.5% from the refrigerant, 8.0% from insulation, and 85.5% from CO₂ emissions. The relative contributions could be affected by three main factors:

- (a) The contribution of insulation and refrigerant to net global warming would vary if CFC-replacements were used. Many CFC-replacements have a direct GWP of 20-30% of CFCs, but without the offsetting effect of ozone depletion, the net effect on global warming impact is negligible. Use of HCFC-123/HCFC-124 would reduce the net warming implications to around 100 Kg CO₂ equivalent (figure 1 ex-

Table 5. The global warming impact of refrigerants and insulants

| Refrigerants and insulants | Ozone depleting potential* | Direct global warming potential** |
|----------------------------|----------------------------|-----------------------------------|
| CFC-11 | 1,0 | 3400 |
| CFC-12 | 1,0 | 7100 |
| HCFC-22 | 0,055 | 1600 |
| HCFC-123 | 0,02 | 85 |
| HCFC-124 | 0,05 | 430 |
| HFC-134a | 0,0 | 1200 |
| R-500 | 0,74 | 5290 |
| CH ₄ | - | 11 |

* Compared to CFC 11

**Compared to CO₂

ample 3). However, using propane or butane as the refrigerant with vacuum panels as the insulator, the *order of magnitude* net warming implication could be around 1 Kg CO₂ equivalent (figure 1 example 4). Alternatively the net warming implication could be reduced by reclamation and recycling of CFCs.

- (b) The relative direct impact from energy consumption could be reduced from 3500 kg CO₂ *order of magnitude*, to 2100 Kg CO₂ from efficiency improvements assessed in developing minimum standards.
- (c) A reduced carbon content of the fuel mix in power generation (reduced coal use and increased gas and renewables) could reduce the overall CO₂ per kWh from around 0.513 Kg CO₂/kWh saved to around 0.445 Kg CO₂/kWh saved. It has been argued that SO₂ emissions in the Northern hemisphere have had a negative forcing of 1.07 Wm⁻² (with an uncertainty factor of 2), compared with the greenhouse gas related positive forcing of 2 Wm⁻² over the period of significant anthropogenic SO₂ emissions (Wigley and Raper 1992). The net effect of reducing SO₂ emissions from power generation, for example through the EC Large Combustion Plant Directive, may actually be to increase the relative contribution of CO₂ emissions from power generation. The effect has not been calculated because of the uncertainties involved.

From the above, while the banning of CFCs from about 1995 will reduce ozone depletion, the effect on global warming is minimal. Banning of halocarbons as a *order of magnitude*, would save 300 Kg CO₂ equivalent per refrigerator. Minimum Standards are predicted to save about 2000 Kg CO₂ on a per refrigerator basis.

4.4. Design for waste reduction and recycling

The net benefit of replacing an inefficient model with an efficient model would be reduced if CFCs from the displaced appliance escaped to the atmosphere earlier than they would otherwise have done. This problem is most appropriately addressed by other policy instruments to encourage recovery and recycling of CFCs on disposal. This is currently performed only in a few locations often with government support. Under current conditions, it is not economic. It has only been possible to reclaim CFC from foam insulation by vacuum shredding. The bonding the inner shell of the appliance to the outer shell with foam insulation has necessitated shredding of appliances in order to reclaim the steel. Options which allow disassembly and clean separation of materials may therefore be cheaper over the whole life cycle given additional legislation to encourage or force recycling.

A possible new insulation technology is vacuum panel insulation (the insulating value of foam is around R 1.4 m²KW⁻¹ for 25 mm of foam, a hypothetical mid-range vacuum insulation is assumed with an insulating value of R 1.76 m²KW⁻¹ in 6 mm (Potter and Benson 1991), although GEA concluded that the cost of introducing vacuum panels to market could not accurately be predicted, so no payback period could be calculated. One form of vacuum insulation uses a metal-envelope, in which the metal envelope could also serve as the Refrigerator steel exterior shell, greatly simplifying construction. Filler materials can include layers of polymer film, gels and powders, spacer arrays, or perhaps some combination of these. The effect on recyclability is not known.

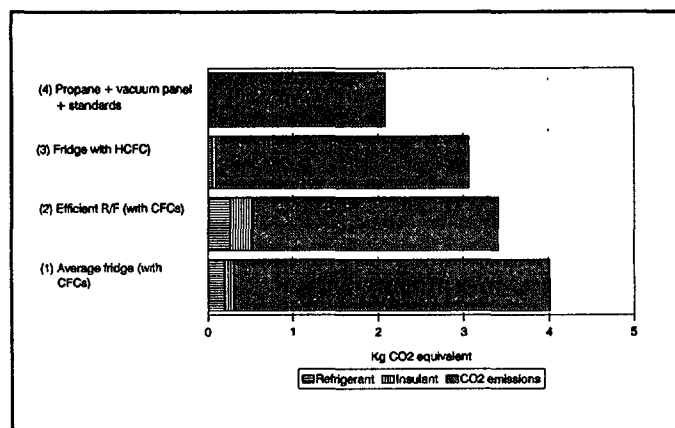


Figure 1. *relative contributions to the global warming impact of a refrigerator*

5. METHODOLOGICAL IMPLICATIONS AND CONCLUSIONS

The aim of this paper has been first, to discuss some of the advantages and disadvantages of expanding the system boundaries of energy efficiency studies beyond energy consumption in use, and second, to discuss examining net impacts rather than gross emissions. In this case the net impact is the total contribution to global warming of refrigerators. A future study might expand the system boundary further, and examine the payback from vacuum panels on energy saved, *plus* reduced global warming and ozone depletion, *plus* materials recovered. In conclusion:

- (a) If energy and other environmental targets are *contradictory*, some prioritisation or conflict resolution might be necessary. One approach might be to cost the impacts associated with each effect, and take the least cost approach (and preferably the least internalised cost). Another option might be to consider mitigation effects at different stages of the life cycle: Energy consumption in use can be reduced by increased insulation. If this implies increased use of CFC-replacement, it does not necessarily imply increased impact, if the CFC-replacement is recovered and recycled at the end of the product life. Options for improvement might not be 'design' options in the strict sense that US DOE and GEA have interpreted the term (ie options built into the product at point of sale). Non-design options might in future need similar technical analysis: legislation on recycling or on designing a refrigerator for disassembly and recycling could make recycling of CFC-replacements more economic.
- (b) If energy and other environmental targets are complementary, including the costs environmental impacts in payback will increase the range of options considered to be economic, including for example, a wider range of refrigerator insulation options. The principle of internalising external environmental costs is impacting utility programmes in the US: power and water utilities already share the costs and benefits of demand side management programmes which fit low-flow shower-heads and toilets on the same visit as installing fluorescent lighting. As part of a demand side programme, Wisconsin Electric collects replaced refrigerators and recycles the components including metal and refrigerant CFCs (Fernstrom, Goldstein et al. 1991).

In addition there are ways in which practitioners of energy studies could contribute significantly to LCA studies:

- (a) LCA studies -particularly those used to support labelling schemes- make the implicit assumption that information is only provided on products already in the market place and not on possible design options. It would be useful to explore the technical and economic analysis of design options used in energy efficiency studies.
- (b) LCA studies frequently assess the impact of an *average* product rather than try to determine the *range of performance* of products. Defining an "average" product is less useful. The range of impacts of a product category needs to be determined to identify the marginal performance, and thus the potential for product improvement.

ACKNOWLEDGMENTS

The author would like to thank Bruce Nordman for hosting a study period at Lawrence Berkeley Laboratories, CA, summer 1992; Benoit Lebot and Andrew Szabo of the Group for Efficient Appliances for their help in calculating the environmental impacts of standards in the EC; and anonymous referees for their constructive comments!

ENDNOTES

- 1. The following assumptions have been made:
 - It is assumed that all CFC is eventually lost to the atmosphere.

- No account of increased energy consumption through degradation of insulation or loss of refrigerant is included.
- No account is taken of the contribution of other emissions from power generation to global warming.

REFERENCES

- Battelle and L. Franklin Associates (Draft). "Product Life-Cycle Assessment: Inventory Guidelines and Principles." Report for The Risk Reduction Engineering Laboratory, US Environmental Protection Agency, Cincinnati Ohio, by Battelle, Columbus, Ohio and Franklin Associates, Ltd Kansas.
- Boustead, I. (1974). "Resource Implications With Particular Reference to Energy Requirements for Glass and Plastic Milk Bottles." *Journal of the Society of Dairy Technology* V 27 N 3 (July 1974) 159-165.
- ENEA (1992). "Study for the Attribution of a European Eco-Label for Refrigerators and Freezers." Italian Ministry for Environment (ENEA).
- Fernstrom, G., D. Goldstein, et al. (1991). "Super Appliance Rebates (Golden Carrots) for More Efficient Appliances: New Incentives for Technological Advances." 42nd International Appliance Technical Conference, University of Wisconsin, Madison May 21-22 1991,
- Fischer, S., P. J. Hughes, et al. (1991). "Energy and Global warming Impacts of CFC Alternative Technologies." Oak Ridge National Laboratory and A D Little, for the US Department of Energy.
- Franklin Associates Ltd (1990). "Energy and Environmental Profile Analysis of Children's Disposable and Cloth Diapers." Diaper Manufacturers Group.
- GEA (1992). "Study on Energy Efficiency Standards For Domestic Refrigeration Appliances- Interim Report." Group for Efficient Appliances, working under ADEME, DEA, and NOVEM (French Danish and Dutch Ministries for Energy).
- Gydesen, A. and D. Maimann (1991). "Life Cycle Analyses of Integral Compact Fluorescent Lamps versus Incandescent Lamps." *Proceedings of the 1st European Conference on Energy Efficient Lighting*, Stockholm, Sweden, Swedish National Board for Industrial and Technical Development, Department of Energy Efficiency.
- Hinnells, M. J. (1993a). "Environmental Impact Analysis of Standards including CO₂ SO_x and NO_x Emissions savings (Appendix 7 in Minimum Standards for Energy Efficiency in Domestic Refrigeration Appliances Final Report.)." Group for Efficient Appliances (Dutch Danish and French Ministries for Energy and the Environment). Report for the Commission of the European Community.
- Hinnells, M. J. (1993b). "Improving the Efficiency of Domestic Electrical Appliances," Evidence to the UK Department of Environment in response to a discussion document, *Climate Change our national programme for CO₂ emissions.* Institute of Advanced Studies, Manchester metropolitan University.
- Hinnells, M. J. Potter S (1993 forthcoming). "Environmental Policy and Consumer Products; plugging them together." in *Policy Studies* journal of the Policy Studies Institute, London, Autumn 1993.
- Lebot, B., A. Szabo, et al. (1991). "Study on the Regulation of Domestic Electrical Appliances." ADEME (French Ministry for Energy and the Environment), Report for Commission of the European Community, Directorate General for Energy.
- Lebot, B., A. Szabo, et al. (1992). "Preparing Minimum Energy Efficiency Standards for European Appliances." ACEEE Summer Study in Energy Efficiency in Buildings, Pacific Grove CA,

- Lehrburger, C. (1988). "Diapers in the Waste Stream, a Review of Waste Management and Public Policy Issues,." Sheffield, MA, quoted in US Congress, Office of Technology Assessment, *Facing America's trash: What next for Municipal Solid Waste?*, Washington DC, 1989, pp116-117,
- Little, A. D. (1990). "Disposable versus reusable Diapers: Health, environmental and economic comparisons." Arthur D Little, report to Proctor and Gamble.
- Muis, H., A. Posthumus, et al. (1990). "Environmental aspects of lighting: a product oriented approach." carried out under the authority of the Ministry of Housing, Physical Planning and the Environment.
- Nordman, B. (1991). "Do Reusable Diapers Use More Energy?" May/June 1991 37-38.
- PA Consulting (1992). "Eco-Labeling criteria for washing machines." PA Consulting (Hemming C, Moody C, Attwood D,) for the DTI.
- Potter, T. F. and D. K. Benson (1991). "Non-CFC Vacuum Alternatives for Energy Efficient Insulation of Household Refrigerators: Design and Use." 42nd International Appliance Technical Conference, University of Wisconsin, Madison May 21-22 1991,
- Roy, R. (1991). "End of Life Electronic Equipment Waste." CEST (Centre for Exploitation of Science and Technology).
- SETAC (1992). "Life Cycle Assessment; Workshop Report." Potsdam, Germany, 25-26 June, Society of Environmental Toxicology and Chemistry- Europe.
- SETAC (1991). "A Technical Framework for Life Cycle Assessments." Washington DC, SETAC.
- Stanton-Hoyle, D. and P. Tseng (1992). "Understanding the CFC Challenge in a Changing World: The Commercial Building Response to the 1990 Clean Air Act Amendments." ACEEE Summer Study in Energy Efficiency in Buildings, Pacific Grove California,
- US EPA (1974). "Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives." Prepared by MRI for US Environmental Protection Agency.
- US EPA (1977). "Fourth Report To Congress." US Environmental Protection Agency.
- US OTA (1989). "Facing Americas Trash, What Next for Municipal Solid Waste." Congress of the United States, Office of Technology Assessment.
- US DOE (1989). "TSD: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces." Produced by the Energy Analysis Program, Lawrence Berkeley Laboratory, for the US Department of Energy.
- US DOE (1990). "TSD: Energy Conservation Standards For Consumer Products: Dishwashers, Clothes Washers and Clothes Dryers." Produced by the Energy Analysis Program, Lawrence Berkeley Laboratory, for the US Department of Energy.
- Whalley, L. (1982). "The effect of changing patterns of materials consumption on the recycling of cars and Domestic Appliances in the UK." *Conservation and Recycling*, Pergamon Press V5 N2/3 pp. 93-106.
- Wigley, T. M. L. and S. C. B. Raper (1992). "Implications for Climate and Sea Level for Revised IPCC Emissions Scenarios." *Nature* V357 (28 May 1992) 293-300.
- Williams, J. (1991). "Disposal of Vehicles: issues and actions." CEST (Centre for the Exploitation of Science and Technology), London.