Increasing effectiveness and efficiency of product energy policy

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Increasing effectiveness and efficiency of product energy policy

Verhogen van de effectiviteit en efficiëntie van het energiebeleid voor producten

(met een samenvatting in het Nederlands)

Proefschrift

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geboren op 14 september 1962 te Bunschoten

Promotor: Prof. dr. K. Blok

Content

1.

Introduction

1.1. Setting the scene: what is this thesis about?

This thesis addresses some of the challenges for product energy policy. In this section we explore and define the subject of this thesis.

This thesis is about (public) energy policy. Several definitions of public policy exist; see e.g. Birkland (2011, p. 8). Two key characteristics of public policy are: first, that a public policy is a policy issued by a public authority, e.g. a government or the European Commission, and second, that a policy has an aim, it is oriented towards a desired state. For a policy to be successful, it must at least have an idea about the current situation, the desired situation and the ways, often called instruments, to achieve the desired situation. Furthermore, this assumes that the desired situation will not be achieved without the public policy, e.g. by market forces on their own (‘business as usual’).

It is well known that the current situation regarding energy needs to change: the effects of our energy consumption, mainly climate change and resource depletion, threaten the way we live on this planet (IPCC 2014). The stakes are high and policies are called upon to change our current unsustainable energy system into a sustainable one, see e.g. GEA (2012). Compared to the current situation the global energy consumption is too high and there is too little energy produced in a sustainable way. **Figure 1.1** shows the world primary energy demand for various scenarios. Both the ‘Current Policy Scenario’ and the ‘New Policy Scenario’ show a steady increase in demand, whereas the demand needs almost to stabilize (‘450 Scenario’) in order to put the world on a path that will stabilize greenhouse-gas concentration at 450 ppm CO_2-eq. Such a level is considered to have a 50 % chance of meeting the goal of limiting the global increase in average temperature to 2 ^{0}C in the long term, compared with pre-industrial levels (IEA 2012, p. 33).

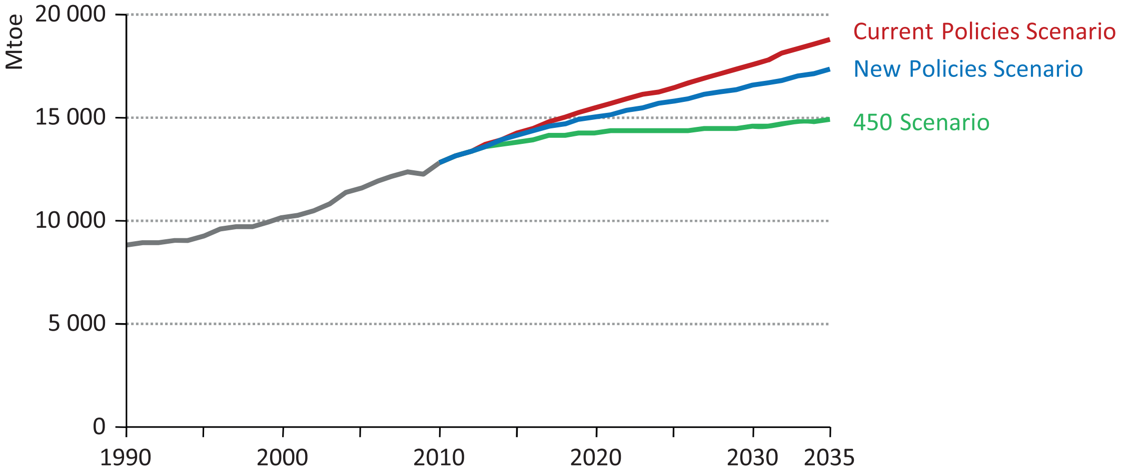

Figure 1.1 World primary energy demand by scenario. Source: IEA (2012, p 50)

According to the International Energy Agency (IEA) World Energy Outlook 2012 which contains a special part ‘Focus on Energy Efficiency’, two third of the reduction in primary energy demand between the ‘Current Policies Scenario’ and the ‘450 Scenario’ comes as a result of efficiency improvements in end-uses (IEA 2012, p. 282). This thesis is about policies that tap into the end-use efficiency potential indicated by the IEA (IEA 2012), the Global Energy Assessment (GEA 2012) and IPCC (2014a). More specific this thesis focuses on certain policy measures for energy using products, e.g. appliances, consumer electronics, office equipment, lighting, electric motors, and heating and cooling equipment. According to Eurostat in 2011, 67 % of final energy was used by installations, equipment, lighting and appliances; the rest (33 %) was used in the transport sector.

Installations, buildings and infrastructures can be seen as systems of (interrelated) products but are not the subject of this thesis. Especially buildings are covered by various energy policies, including the use of renewables; in the EU e.g. by the Energy Performance of Buildings Directive[1] (EPBD). In general building codes give freedom to the constructor on how to achieve a required energy performance: more insulation to reduce the energy demand for heating and/or cooling, a more efficient heating and cooling installation, including the use of renewables, or a combination of both approaches. The trend towards (near) zero energy buildings as required in the EU by the EPDB will reduce

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[1] Official Journal of the European Union (OJ) L (series) 153, 18.6.2010, p.13-35. A Directive is one of the forms of secondary legislation in the EU.

the relevance of the energy consumption of heating and cooling installations. Assuming that the total natural gas consumption in the EU could be avoided by building energy policies then, according to Eurostat data (European Commission 2013), energy using products excluding means of transport would still use 45 % of EU final energy consumption in 2011[2].

Saving potentials for energy using products are large. Desroches and Garbesi (2011) studied the maximum technical energy efficiency potential for household appliances, consumer electronics, information and communication technology products, lighting, commercial and industrial products. The reduction in primary energy use by replacing a current average product with a best-on-the-market product varied from 6 % for medium electric motors to more than 70 % for e.g. washer extractors and commercial steamers. For 19 products the maximum technical potential savings per product compared to the current average on the market were estimated. These ranged from 20 % (refrigerators) to more than 80 % for e.g. televisions, low-end servers and clothes washers. Chapter 9 of the contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2014a, p. 25) found potential energy savings percentages between 30 and 90 for household appliances, lighting and equipment[3].

Policy measures for energy using products can be categorized as follows:

- The *nature* of the measure (as set by the public authority): voluntary, mandatory, supportive.
- The *type* of the measure: information, financial, product conformity[4].

Voluntary measures are actions that are taken by actors without the policy maker forcing the actors to do so, e.g. a voluntary agreement by industry to provide information on energy consumption with the product. Of course policy makers can stimulate and support

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[2] Total final energy consumption in 2011: 1103.3 Mtoe of which 739.2 Mtoe (67 %) other than transport. Total final gas consumption in 2011: 241.1 Mtoe, resulting in 498.1 Mtoe final consumption other than transport and gas, which is 498.1/1103.3 = 45 %.

[3] In most cases the base line for the savings was the current average product on the market. In some cases savings percentages were based on international comparison of average products, or on behavioral change. A few cases did not mention the base line.

[4] Compliance with standards, rules or laws.

voluntary measures and even provide guidelines or requirements (see e.g. Annex VIII of the Ecodesign Directive[5]). However, ultimately it is the decision of the market actors to enter into a voluntary agreement or not. Mandatory measures are obligatory for all manufacturers of products that are within the scope of the measure. Supportive measures by public authorities are not *directly* targeted at the product but support actors to develop, make and market products that contribute to the policy goal. An example of a supportive information measure is setting up a public database with basic information on products. Websites subsequently can use this information giving advice on energy efficient products.

Table 1.1 provides an overview of the categories of policy measures for energy using products and the grey cells indicate the measures addressed in this thesis.

Table 1.1 Categorization of policy measures for energy using products

		Nature of measure		
		Voluntary	***Mandatory***	***Supportive***
Type of measure	***Information***	Voluntary energy label	Mandatory labels	Making basic information available
	Financial	Rebate programme by utility	Taxes	Subsidies for pre-competitive research
	Product conformity	Voluntary agreement by manufacturers	Minimum efficiency performance standards	Public research centers

The main reasons to focus on these measures is that mandatory minimum efficiency performance standards (MEPS) and labels are the most widely used product policy measures for energy efficiency (WEC 2013, p. 44-45)[6]. According to a study for the Australian department of industry (EES 2013) the number of countries with a standards and labeling programme has grown from 50 in 2004 to 81 in 2013. The number of standards and labeling measures has increased from 1220 in 2004 to 3601 in 2013,

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[5] OJ L285, 31.10.2009, p.10-35. The Ecodesign Directive is the framework directive for setting minimum efficiency performance standards in the EU, see section 1.2.3.

[6] In 2012 around two third of the measures are of the regulatory type (WEC 2013, p. 44) of which more than 80 % are standards and labels (WEC 2013, p. 45).

however the number of *voluntary* energy performance standards worldwide decreased by 33 % from 2004 to 2013.

The situation in the EU reflects the above: mandatory MEPS and energy labels are the most common product efficiency measures. Although in some Member States voluntary energy labels operate, e.g. the Energy Savings Recommended label in the UK, the only voluntary energy label operating at the EU level is the ENERGY STAR label which in the EU is restricted to office equipment. Rebate programmes by utilities exist; in the EU mostly in the framework of white certificate schemes (Bertoldi et al. 2010) but often are limited in duration, geographical coverage and product coverage. Voluntary agreements by manufacturers on product efficiency are scarce. Although the Ecodesign Directive stimulates self-regulation initiatives, so far only two initiatives are in operation (complex set-top boxes and imaging equipment). The main reason is that manufacturers, who in principle have a positive stance on voluntary agreements, have concerns about the enforcement and avoidance of free-riders (CSES 2012, p. 148, CECED 2007). Differentiation of taxes, e.g. a lower VAT level for energy efficient products, has been studied (BIOIS 2008) and has been applied in some Member States. Regarding supportive measures, subsidies for pre-competitive research are applied at the EU level through e.g. the FP7 programme[7]. FP7 has an energy component but this is mostly focused on (renewable) energy production and conversion.

Although standards and labels are applied worldwide, this thesis is mainly written from an EU perspective. The main reasons are the following. First, literature on standards and labels in the EU, including the process to prepare and adopt these measures, is scarce and mostly relates to the (design of the) energy label, e.g. Winward et al. (1998), Heinzle (2012)[8]. Second, since in the EU MEPS and the energy label for a certain product are prepared in the same process, this provides a unique opportunity to study both measures together. Third, in the EU products are subject to EU internal market rules. So, mandatory measures which in principle restrict the placing on the market or putting into service of

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[7] Since 2014 integrated in Horizon2020 (http://ec.europa.eu/programmes/horizon2020/).

[8] Schiellerup (2002) is an exemption, but deals only with the impact in the UK of EU MEPS for cold appliances.

products can only be set at the EU level[9] and not by individual EU Member States[10]. Finally, it is a practical restriction to keep the scope of this thesis manageable. However, this does not mean that experiences in other parts of the world are ignored. On the contrary, comparing the EU data and experiences with those in other parts of the world is one of the methods used in this thesis to address the challenges for product energy policy. Furthermore, since ever more products are produced for a world wide market, coordination and harmonization of (parts of) standards and labeling programmes will get more attention from industry and policy makers. Therefore, the results of the research presented in this thesis have a broader relevance than for the EU only.

The subject of this thesis can now be stated as follows: mandatory policy measures on product information and product conformity to reduce energy consumption of energy using products.

The next section of this introductory chapter provides provide a short historical overview, including the current status, of EU product energy policy[11]. Section 3 of this chapter provides some theoretical considerations regarding product energy policy to structure the challenges addressed in this thesis. Finally section 4 indicates some of the challenges for product energy policy and how these are addressed in the following chapters. The final chapter takes stock of the results of the individual chapters and draws conclusions and provides recommendations on a more general level.

1.2. A short history and current status for EU product energy policy

1.2.1. Introduction

Although two of the originating institutions of the EU, the European Coal and Steel Community and Euratom, dealt with energy, the Community energy efficiency policy or policy for the rational use of energy as it was called in the beginning has a shorter history[12].

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[9] Individual Member States can only maintain or introduce (more stringent) requirements under certain conditions (see Article 114, 4-7 TFEU) and approval by the European Commission.

[10] This is contrary to the situation in the US where development of measures at State level, especially California, often drives or influences Federal standards activities.

[11] For the US see US DOE (2006) or Geller et al. (2006).

[12] For an overview of EU law, see Davies (2013).

On 17 September 1974 the Council[13] adopted a resolution concerning a new energy policy strategy for the Community[14] [15] which included a guideline regarding energy demand as to reduce the rate of growth of internal energy consumption by measures for using energy rationally and economically without jeopardizing social and economic growth objections. In the same resolution the link between both production and consumption of energy and environmental protection was stressed. This resolution was followed on 17 December 1974 by a Council resolution on a Community action programme on the rational utilization of energy[16] that adopts the objective of reducing the medium-to-long-term growth rate of energy consumption for the Community as a whole and notes that the Commission will submit appropriate measures to the Council. Consequently on 4 May 1976 the Council adopted five recommendations on the rational use of energy

- by promoting the thermal insulation of buildings (76/492/EEC)
- in the heating systems of existing buildings (76/493/EEC)
- through better driving habits, of energy consumed by vehicles (76/494/EEC)
- in urban passenger transport (76/495/EEC)
- for electrical household appliances (76/496/EEC).

In these five recommendations the three focus areas for non-industrial efficiency policy can be recognized: buildings, transport and appliances and installations. These recommendations were the basis for the two types of measures that are well known today: minimum efficiency requirements and energy labels; see next sections.

Not until 2000 the Commission published the Action Plan to Improve Energy Efficiency in the European Community (European Commission 2000). This plan described actions to strengthen the energy label and announced both the preference of negotiated agreements as an alternative for mandatory minimum efficiency standards and the presentation of a framework directive to set mandatory minimum efficiency standards if necessary. The Action Plan for Energy Efficiency: Realising the Potential (European

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[13] Council of Ministers (of Member States). The Council is one of the two legislative powers in the EU, the other one is the European Parliament.

[14] OJ C 153, 9.7.1975, p. 1.

[15] At that time the European Economic Community (EEC).

[16] OJ C 153, 9.7.1975, p. 5.

Commission 2006, p. 10) indicated as Priority Action 1 Appliance and equipment labelling and minimum energy performance standards. Contrary to the 2000 action plan it focused completely on mandatory minimum efficiency measures under the Ecodesign Directive[17] since the few voluntary initiatives that existed were not renewed (CECED 2007) and no new voluntary initiatives were brought forward. It further announced the revision of the EU labelling scheme to enlarge the scope. The Energy Efficiency Plan 2011 (European Commission 2011a) repeated the importance of minimum efficiency measures under the Ecodesign Directive and energy labelling measures to deliver energy savings for consumers and business opportunities for European manufacturers. Connected with the scope of this thesis we follow in the next sections in more detail the evolution of mandatory minimum efficiency requirements and energy labelling for products, excluding means of transport.

1.2.2. Energy labelling

Council Recommendation 76/496/EEC on rational use of energy for electrical household appliances recommended to the Member States to adopt “energy labels”, i.e. a label on which the unit energy consumption is indicated, for each electrical household appliance listed in the Annex. Apparently this recommendation resulted in different schemes in various Member States and thereby creating non-tariff barriers to intra-Community trade in household appliances. Therefore, Council Directive 79/530/EEC of 14 May 1979 on the indication by labelling of the energy consumption of household appliances[18] established the first framework Directive for energy labelling in order to harmonize “national regulations on the publication, particularly by means of labelling, of information on energy consumption”[19]. However this labeling system was not mandatory for Member States. The only implementing directive adopted under this framework directive was the Council Directive 79/531/EEC of 14 May 1979 for electric ovens[20] (see **Figure 1.2**) and this label was introduced only by a few Member States. Note that this energy label did not use a classification.

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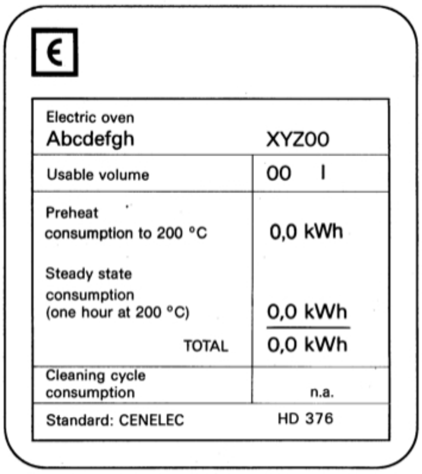
[17] Framework legislation that is used in the EU to set mandatory MEPS for products.

[18] OJ L 145, 13.6.1979, p. 1.

[19] OJ L 145, 13.6.1979, p. 2.

[20] OJ L 145, 13.6.1979, p. 7.



Electric oven Abcdefgh	XYZ00
Usable volume	00 l
Preheat consumption to 200 °C	0,0 kWh
Steady state consumption (one hour at 200 °C)	0,0 kWh
TOTAL	0,0 kWh
Cleaning cycle consumption	n.a.
Standard: CENELEC	HD 376

Figure 1.2 Energy label for ovens

Therefore the second framework directive, Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances[21], introduced a framework for adopting *mandatory* energy labels for a list of household appliances. The directive itself did not define any energy labels but provided for the procedure to adopt product directives with an energy label for that product, including the aspects to be specified in the directives. The implementing directives adopted under this framework directive introduced the well known European energy label (see **Figure 1.3**, left hand side) for the following products: refrigerators and freezers, washing machines, washer-driers, dishwashers, ovens, driers, air conditioners and lamps.

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[21] OJ L 297, 13.10.1992, p. 16.

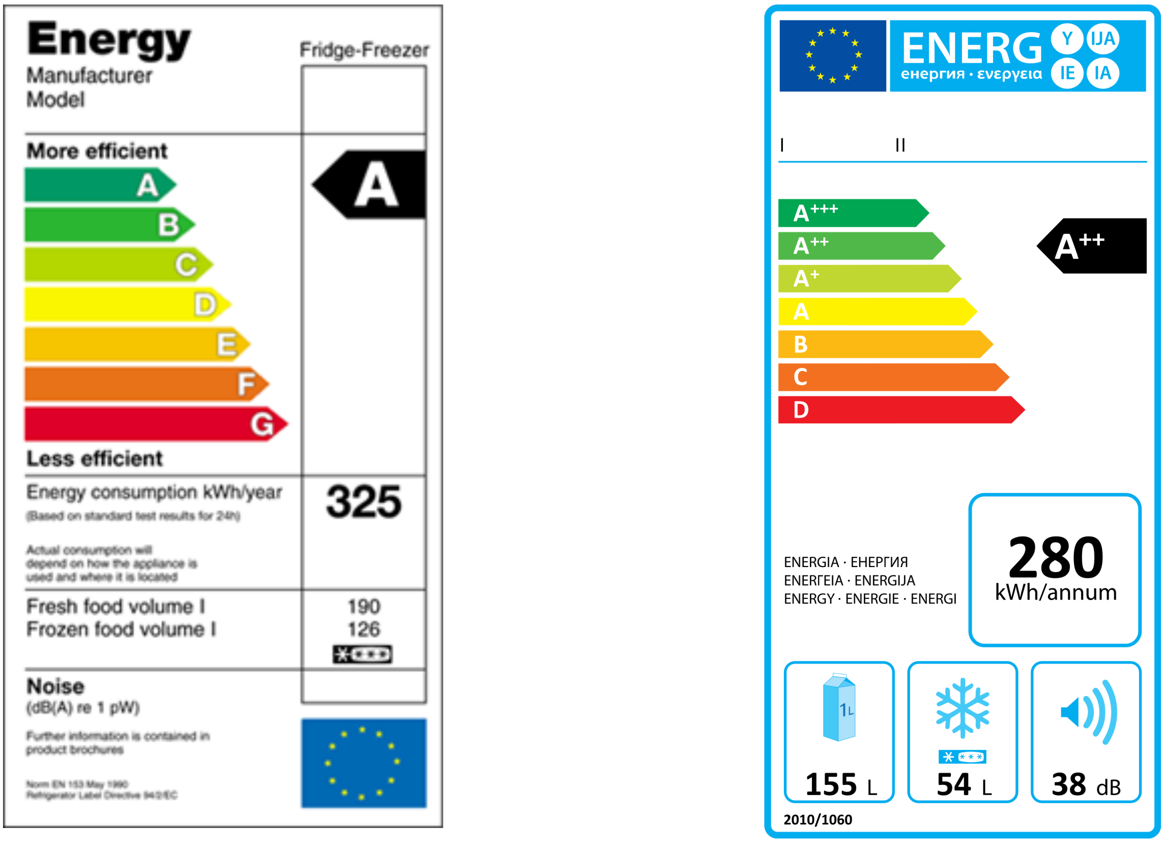

Figure 1.3 Old and new EU energy label for refrigerators

The success of the European energy label in transforming the market towards more efficient appliances (European Commission 2008) made clear the limitations of this framework directive: the restricted scope, no guidelines for the lay-out of the energy labels and focus on sales via physical shops. Therefore the third framework directive, Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products[22], introduced the following changes:

- extension of the scope to energy-related products
- the language neutral label (see **Figure 1.3**, right hand side)
- the A+, A++ and A+++ classes on top of the A-G scale
- advertisements of specific models shall include the energy class.

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[22] OJ L 153, 18.6.2010, p. 1.

In the years following the publication of Directive 2010/30/EU, the new energy label replaced the energy labels adopted under Directive 92/75/EEC (except for washer-driers) and new labels were introduced for televisions, boilers, combi-boilers and water heaters, vacuum cleaners and range hoods. According to the directive the Commission has to evaluate the effectiveness of the directive not later than 31 December 2014.

1.2.3. Minimum efficiency requirements[23]

Council Directive 78/170/EEC of 13 February 1978 on the performance of heat generators for space heating and the production of hot water[24] required that Member States shall take all necessary measures to ensure that all new heat generators comply with minimum performance requirements. However the Directive did not specify this minimum performance requirements and one of the recitals[25] for Council Directive 92/42/EEC of 21 May 1992 on efficiency requirements for new hot water boilers fired with liquid or gaseous fuels indicated that Directive 78/170/EEC "has given rise to the establishment of substantially different efficiency levels between one Member State and another"[26]. These substantially different efficiency levels created unwanted trade barriers between Member States. Because in 1992 the (completion of the) internal market[27] was a high priority, Directive 92/42/EEC contained mandatory minimum efficiency requirements for boilers. Moreover this Directive contained a star system as energy-performance label, awarding between one and four stars depending on the efficiency achieved where the one star label represented the minimum efficiency requirements. However, contrary to the minimum efficiency requirements, the energy-performance label was not mandatory; Member States were free to apply the star system, but if they applied these labels they must apply to all boilers placed on their market. Other Directives containing mandatory minimum efficiency requirements were Directive 96/57/EC of 3 September 1996 on energy efficiency requirements for household electric refrigerators, freezers and combinations thereof[28] and Directive 2000/55/EC of 18 September 2000 on energy

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[23] In the EU the word 'requirements' is used to indicate 'standards'.

[24] OJ L 52, 23.2.1978, p. 32.

[25] Part of the directive that explains its purpose.

[26] OJ L 167, 22.6.1992, p. 17.

[27] Uniting the markets of the Member States into a single economic area without internal frontiers (Davies 2013).

[28] OJ L 236, 18.9.1996, p. 36.

efficiency requirements for ballasts for fluorescent lighting[29]. However this system of individual directives was not found satisfactory and inspired by the framework directive on energy labeling, Directive 2005/32/EC of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products[30] was adopted. This directive did not set ecodesign requirements but provided for the procedure to adopt measures for specific products, including the criteria for which products a measure was to be adopted[31] and the aspects to be specified in a measure. In principle requirements should be set for all relevant environmental aspects of a product, i.e. aspects that have a significant environmental impact and present significant potential for improvement. However, because the scope of the directive was energy-using products, the energy consumption of the product during use was always included in the requirements. Therefore, this directive can be considered the EU legislative framework for setting minimum efficiency performance standards. The directive was recast in 2009 to allow for setting ecodesign requirements for energy-related products (Directive 2009/125/EC of 21 October 2009 establishing the setting of ecodesign requirements for energy-related products (recast)[32]).

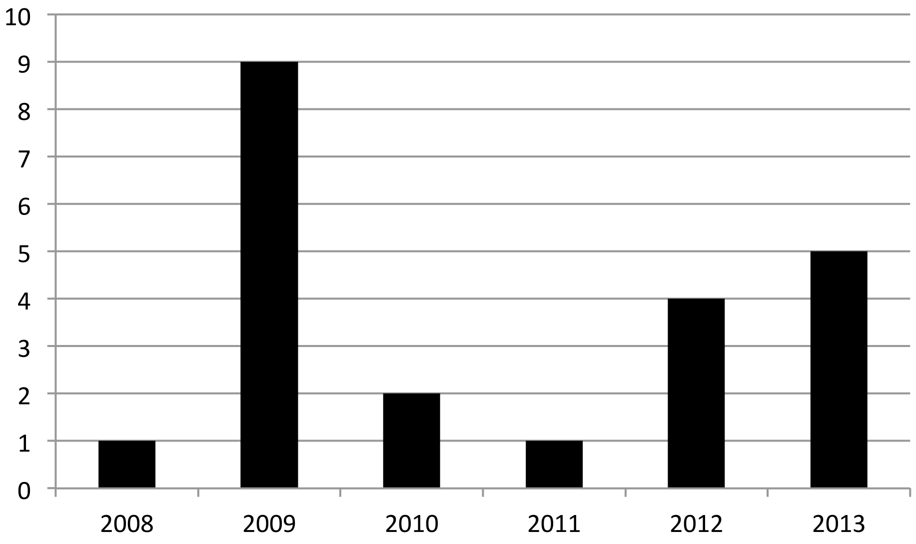

Figure 1.4 Number of ecodesign regulations published per year

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[29] OJ L 279, 1.11.2000, p. 33.
[30] OJ L 191, 22.7.2005, p. 29.
[31] As an alternative for (mandatory) regulations, the Ecodesign Directive also allows for self-regulation initiatives by industry.
[32] OJ L 285, 31.10.2009, p. 10.

Figure 1.4 shows the number of measures that have been published in the Official Journal under both directives. According to the most recent studies it is estimated that the savings from these measures are 6688 PJ/year in 2020, corresponding to approximately 19 % of total EU energy consumption from these product groups in 2020 (Molenbroek et al. 2014, p. 21).

The Ecodesign Directive was reviewed in 2012 (CSES 2012). This review did not result in a proposal to change the directive. Furthermore, since at the time of this review the recast directive was only in force for two years, it was decided that certain aspects of the directive would be assessed together the with the review of the Energy labelling Directive in 2014.

1.2.4. Other product policies

Besides mandatory minimum efficiency requirements and energy labels, other product policies that relate to the energy use of products exist at the EU level. Furthermore, other energy efficiency policies, e.g. the Energy Performance of Buildings Directive[33] and the Energy Efficiency Directive[34], relate to the efficiency of products, as can do environmental policies, e.g. the WEEE Directive[35], the RoHS Directive[36] and the REACH Regulations[37]. This section shortly describes some voluntary policies at EU level that are related to ecodesign and energy labelling.

The ***EU Ecolabel***[38] sets requirements on environmental aspects, including energy if relevant, for more than 30 product groups of which 5 are energy-related. The use of the Ecolabel is voluntary and manufactures have to pay a fee for the use of the label. Ecolabel requirements for energy consumption refer to energy label classes. Regarding energy efficiency requirements, the Ecolabel measures refer to energy labelling classes or ENERGY STAR specifications where available. If a product has an Ecolabel, the manufacturer may show this in the energy label of the product.

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[33] OJ L 153, 18.6.2010, p.13-35.
[34] OJ L 315, 14.11.2012, p. 1-56.
[35] OJ L 197, 24.7.2012, p. 38-71.
[36] OJ L 37, 13.2.2003, p. 19-23.
[37] See http://ec.europa.eu/enterprise/sectors/chemicals/documents/reach/index_en.htm.
[38] OJ L 27, 30.1.2010, p. 1-19.

In the framework of ***Green Public Procurement*** (GPP)[39] criteria on environmental aspects have been developed for 18 product groups of which 9 are energy-related. Public authorities can use these criteria when procuring goods, services and works with a reduced environmental impact during throughout their life cycle.

The ***Energy Star*** Agreement[40] and the Energy Star Regulation[41] regulate the use of the ENERGY STAR label for office equipment in the European Union. The ENERGY STAR label is a voluntary label that manufacturers can use for products that meet the ENERGY STAR specifications for that product. In general the specifications aim to award not more than the 25 % most efficient models according to market data available at the time of setting the specifications. ENERGY STAR specifications have been published for computers, displays and imaging equipment. The specifications for computers are also used for an ecodesign regulation for computers[42] and the specifications for imaging equipment are used in a voluntary agreement under ecodesign[43].

Product Environmental Footprint (PEF)[44] aims to establish a common European methodology to assess the environmental impact of products, including carbon. This methodology is tested in 14 pilot projects to set up product footprint category rules. These rules should allow for labelling and benchmarking the environmental performance of these products. Although ecodesign in principle covers all environmental impacts of a product, in practice assessing other impact than the energy consumption during use has been limited, one of the reasons being the lack of methodologies to assess other environmental aspects for a mandatory measure (CSES 2012). PEF could help to fill this gap.

1.3. Theoretical background

“There is nothing so practical as a good theory" (Lewin 1951, p. 169). Although every policy measure is – implicitly – based upon theoretical considerations, explicit theory on product energy policy is scarce and scattered. A single, integrated theoretical framework

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[39] See http://ec.europa.eu/environment/gpp/index_en.htm.
[40] OJ L 63, 6.3.2013, p. 5-80.
[41] OJ L 63, 6.3.2013, p.1-4.
[42] OJ L 175, 27.6.2013, p.13-33.
[43] See http://www.eurovaprint.eu/pages/voluntary-agreement/.
[44] See http://ec.europa.eu/environment/eussd/smgp/product_footprint.htm.

does not exist. This thesis does not aspire to present such a framework. However, to structure some of the theoretical considerations and assumptions related to product energy policy, some of which are scrutinized in this thesis, the model of **Figure 1.5** is used. This model consists of two sections that are linked up by measures, information and energy consumption: a policy section and a product section. The policy section encompasses goal setting, preparing and adopting measures, the product section designing, manufacturing, selling and using products, focusing on energy consumption during use of products. Measures, information to prepare measures and energy consumption data link the policy section with the product section.

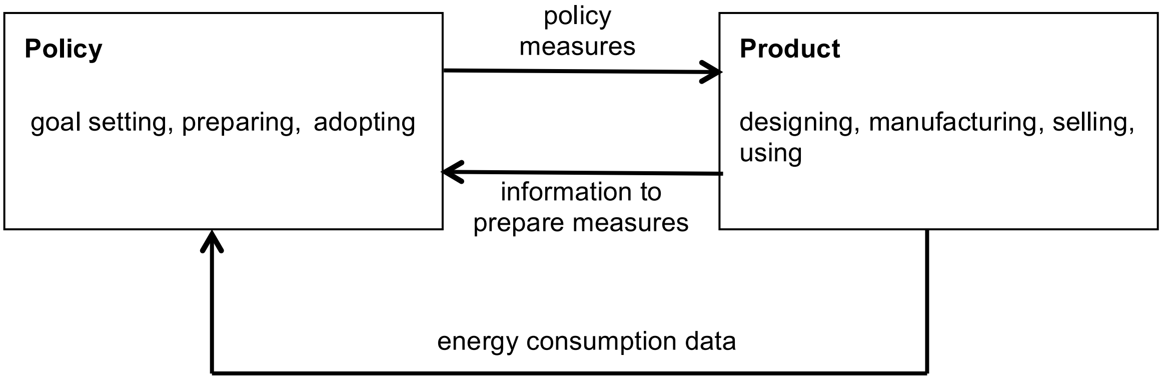

Figure 1.5 Product energy policy model

1.3.1. The policy section

The policy section has a political component and a methodological component. In general the ***political component*** assumes a democratic, participatory process of which the (ideal) characteristics are amongst others transparency, consultation and involvement of stakeholders, and evidence-based (Voermans 2009, p. 71). Regarding the EU energy labelling and ecodesign measures, both framework directives guide the process of preparing and adopting measures[45]. Due to the large number of measures that has been adopted (see **Figure 1.4**) and is still to be adopted, the ongoing evaluation of the Energy labelling and Ecodesign Directives also is paying attention to the efficiency of the process, including the duration (Molenbroek et al. 2014).

The ***methodological component*** includes the choice of the type and nature of measures

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[45] See also section 6.2. For the US DOE process for setting standards, see US DOE (2006, p. 18-31). For the process for preparing and adopting Top Runner measures in Japan, see METI (2010).

and the method to develop measures. A theoretical framework that guides the choice of measures on product energy consumption is the market transformation framework (Geller and Nadel 1994). This framework shows with which instruments the efficiency distribution of products on the market can be moved towards greater efficiency. R&D subsidies stimulate the development of new efficient products, public procurement and energy labels stimulate the sales of the most efficient products on the market and minimum efficiency performance standards (MEPS) remove the products with the worst efficiency from the market. For on-going efficiency improvement the measures should be revised regularly.

As indicated in section 1.1, this thesis focuses on mandatory energy labels and especially MEPS. Several methods for developing MEPS exist, e.g. the MEErP[46] methodology used in the EU ecodesign process (Kemna 2011) or the methodology used by the Department of Energy (DOE) in the US (US DOE 2006). A crucial step in these methods is the setting of the MEPS level, i.e. the maximum energy consumption or minimum energy efficiency that is allowed for products to stay on the market. Several methods that guide the setting of this level are available. In the EU and the US life cycle cost analysis is used. The life cycle costs of a product are the sum of the purchase price and the discounted energy and other operating costs over the lifetime of the product, including disposal costs at the end of life[47]. It is assumed that increasing the efficiency of the product increases the purchase price and decreases the energy costs (see **Figure 1.6**). So with increasing efficiency the life cycle costs will decrease first because the increase of the purchase price is less than the saved energy costs. After reaching a minimum (LLCC: least life cycle costs) they will increase because the increase of the purchase price is no longer compensated for by saved energy costs. At some point the life cycle costs will be equal to those of the (less efficient) product the analysis started with (ELCC: equal life cycle costs). The most efficient product that can be designed with best available technology (BAT) may have life cycle costs greater than the ELCC. To achieve most energy savings and make the end-user not paying more, the MEPS level should be set between the LLCC and the ELCC. The life cycle cost curve can also guide the setting of levels for the energy label classes. If the

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[46] MEErP: Methodology for Ecodesign of Energy-related Products.

[47] If the product has a rest value these costs can be negative.

MEPS is set at the LLCC level, the lowest efficiency class lies just above this level. The highest efficiency class can be set at or just above the BAT level. The Top Runner programme in Japan uses another method for setting target levels. The target level is the efficiency of the most efficient product on the market at the time of the analysis[48].

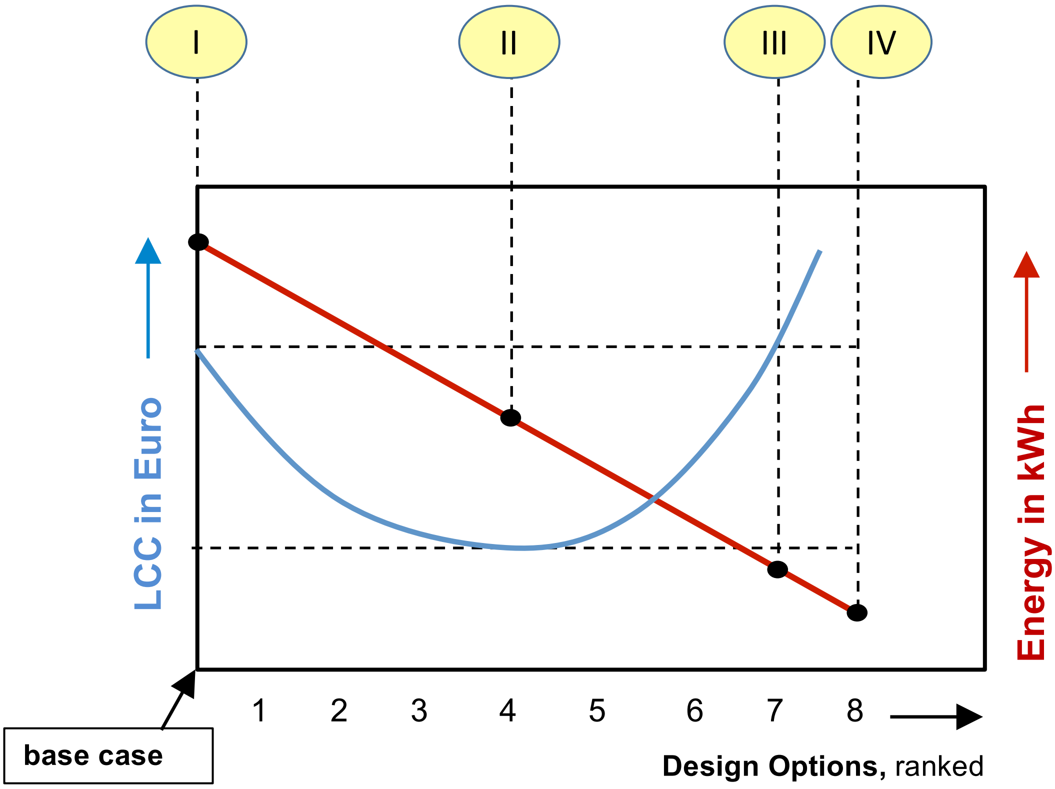

Figure 1.6 Archetype LCC curve (Kemna 2011, p. 136). I=base case; II=LLCC; III=ELCC; IV=BAT.

1.3.2. The product section

The product section in fact consists of two parts that are closely connected: the producer and seller part, and the buyer and user part. Information from the product section is necessary for the policy section to prepare and adopt effective measures in an efficient way. Regarding the producer and seller part, two important aspects for policy making are the (re)design cycle and costs. The (re)design cycle affects the timing of measures, e.g. under the Ecodesign Directive the date of entry into force of the requirement must take

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[48] This is the main criterion for setting the target level. As will be shown in chapter 3 Top Runner uses additional criteria to fine-tune the target level.

the redesign cycle for the product into account[49]. The design and preparation of the production of a product costs time. The manufacturer more easily handles requirements on product efficiency that need changes in the product design if they coincide with the design phase. Therefore besides the MEPS level or the energy class level itself, the entry into force date is an important parameter of a policy measure. Delaying the entry into force data can compensate setting more stringent MEPS.

As shown in section 1.3.1, costs are essential input for the LCC calculations that guide the setting of MEPS. However, cost data often are not publicly available because they are considered commercially sensitive information, and therefore the price of the product is taken as a proxy for the costs of a product; see section 4.2.2 for a more detailed discussion. Costs are often assumed to be constant (in real prices) but it has been shown that this assumption does not hold (Dale et al. 2009). As a consequence the LCC calculations should use dynamic costs.

Furthermore, policy rules in the EU and Japan do not allow MEPS levels that can only be achieved with one single, patented technology.

Ultimately, products are designed and manufactured to be used. And the energy consumption that is to be regulated by policy measures is the energy consumption during use. Use patterns and times influence life cycle costs and by that the available options for measures. An important assumption is that products are used for their functionality. As a consequence the function or performance of a product is often taken into account when evaluating the energy consumption; not the energy consumption itself but the efficiency, the performance per unit of energy consumption, is regulated. However, improvement of energy efficiency does not automatically mean lower energy consumption: the efficiency also improves when the energy consumption increases but the performance increase is larger than the consumption increase. The above also assumes that the product and the functionality can be defined unequivocally and that the functionality does not change during the lifetime of the product. However, this is becoming ever more a challenge because almost all products are equipped with microprocessors and are software controlled. As a result, functionality can be changed by installing updated software, e.g. through a network connection.

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[49] OJ L285, 31.10.2013, p.26.

1.3.3. Measures and energy consumption

Measures link the policy section and the product section. Information on the design, manufacturing, selling and use of products is necessary to prepare effective measures in an efficient way (see sections 1.3.1 and 1.3.2). In turn these measures aim to influence the design, manufacturing, selling and use of products in such way that the energy consumption during use is reduced.

Energy consumption, and changes therein, is the main feedback from the product section to the policy section. Ex ante saving estimates are used to indicate the effect of a measure before it is adopted; in the EU such estimates are included in the impact assessment of the measure and in the recitals of the regulation. Savings estimates after the measures have come into force (ex post) are scarce; see e.g. Winward et al. (1998) for the EU energy label, Meyers et al. (2003) for US DOE appliance standards or Sanchez et al. (2006) for savings for the ENERGY STAR programme. Certainly assessing the real savings, i.e. the savings when the products are in use at the end-users, is complicated[50]. It also illustrates the limitations of (current) product energy policy measures seen in the light of reducing (total) energy consumption (Harris et al. 2008). First, setting requirements on efficiency does not automatically mean a proportional decrease in energy consumption. Second, measures cannot or only in a very limited way, e.g. through default settings, control the use of a product. A product that is used longer or more frequently will use more energy regardless the efficiency of the product. Third, product measures target individual products whereas the number of products in use also determines total energy consumption. So the total consumption of a small number of inefficient products can be lower than the total consumption of a large number of efficient products. Finally, verification and enforcement of measures must be mentioned. Without proper verification and enforcement part of the predicted savings are lost because not all products will meet the requirements and/or have the correct energy label. It is estimated that in the EU with the current level of enforcement in Member States around 10 % of the savings of mandatory product measures is lost (MarketWatch 2012).

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[50] Even measuring energy consumption of products in real life is a complex and expensive undertaking, see e.g. EURECO (2002) and REMODECE (2009) for the EU, Zimmermann (2009) for Sweden, Zimmermann et al. (2012) for the UK, Greenblatt et al. (2013) for California.

By explicitly separating the policy and product section, **Figure 1.5** illustrates an important issue in product policy making: information asymmetry. For policy makers the product part is to a large extent a black box; especially information on technology and cost development is hard, if not impossible to get. These are not imperfections of the process that can be cured, but are inherent to a free market with competition. Although on the other hand the policy part should be transparent and participatory, in practice policy processes can be fuzzy and hard to follow for those that are not directly involved. This means that certainly for individual, smaller manufacturers the policy part is a grey box. And even when a measure has been published, it can take some time before all addressees are aware of the measure and its consequences.

1.4. Challenges for product energy policy and how these are addressed in this thesis

Product energy policy should provide a significant contribution to the reduction of energy consumption; see European Commission (2006, 2011a) for the EU, METI (2010) for Japan and Executive Office of the President (2013) for the US. This goal poses a number of challenges for product energy policy that can be summarized in two categories:

1. Effectiveness, relating to the energy savings that the measures deliver.
2. Efficiency, relating to the time needed for process of preparing and adopting measures[51].

The aim of this thesis is to show how the effectiveness and the efficiency of product energy policy can be increased. The rest of this section provides for each of the chapters the specific research questions.

Learning from other countries can be an important way to increase the effectiveness and efficiency of policy measures. Mapping energy efficiency indicators over time and comparing them between countries (benchmarking) has been done for industry, transport and buildings, but not for the products that are dealt with in this thesis such as appliances and electronic products. Chapter 2 (***International benchmarking of products for policy makers***) addresses this knowledge gap by developing and demonstrating a

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[51] Note that the term “efficiency” only indicates the adequacy of the process and does not include economic connotations.

method for mapping and benchmarking product efficiency data from different countries. The related research question is: what are the conditions that need to be fulfilled in order to compare results from different countries in a fair way? The answer then is used to compare results from MEPS and energy labels for three major household appliances (cold appliances, washing machines and laundry driers).

As indicated in section 1.3.1 Japan uses a different approach for setting MEPS than the EU: the top runner approach. However, detailed information on the Top Runner programme and its results in the English language domain is scarce. Furthermore, although the Top Runner programme is often cited as an example for the EU to follow, a systematic comparison of the Japanese Top Runner programme and the EU Ecodesign scheme is lacking. Chapter 3 (***Top Runner and Ecodesign***) fills this gap and addresses the research question of what the Top Runner and Ecodesign schemes can learn from each other by comparing these schemes both regarding the effect on energy consumption of products and the process.

Life cycle cost calculations have a pivotal rule in the methodology for setting MEPS. As indicated in section 1.3.2, earlier research showed that life cycle cost calculations for setting MEPS should use dynamic costs. Dynamic costs can be modeled by experience curves, indicating that product cost is decreasing in time with increasing cumulative production. However, what is missing is the integration of experience curves into life cycle cost calculations. Chapter 4 (***The role of experience curves for setting MEPS***) provides this missing link by developing two methods to integrate experience curves into the life cycle cost calculations to set MEPS levels. It demonstrates these methods for laundry driers and refrigerator-freezers and estimates the additional energy savings this would deliver. It is also shown how energy label classes can be useful in setting MEPS.

Electronic products, consumer electronics and information and communication technology products, make up an increasing share of electricity consumption. To increase the effectiveness of product energy policy in general, measures for these products need to be prepared and adopted. As we showed in section 1.3.1 life cycle cost analysis is used to guide the setting of MEPS levels. A crucial assumption herein is that the efficiency of the product is positively related to product price. However, as a result of the research presented in chapter 4, the question arises whether this relation also holds for electronic products. Chapter 5 (***Setting MEPS for electronic products***) addresses this research question, and aims to provide an alternative method of setting MEPS in case price and efficiency are not related. Since the high speed of market developments is one of the characteristics of most electronic products, the timing of measures is critical for their effectiveness. To guide the maximum time that is available for preparing and adopting measures, chapter 5 introduces the concept of the policy action window (PAW). The PAW can be used to set priorities and increase the efficiency of the process when dealing with multiple candidate products for policy measures.

Preparing and adopting ecodesign and energy label measures in the EU often costs more time than was planned for. With ever more measures or revisions of measures being prepared, the efficiency of the process – expressed in the duration of the process – requires due attention. Delays in the process are not unique for the EU[52], but the reasons for the delays and the effects on energy savings have not been investigated. Chapter 6 (***Analyzing delays in preparing and adopting ecodesign and energy label measures***) addresses this knowledge gap, guided by the following research questions: what are the reasons for the delays in preparing and adopting ecodesign and energy label measures, what are the lost savings and how can the efficiency of the process be improved? The last question is answered by comparing the EU process with that in the US and Japan.

Product innovation, especially regarding electronics, software and networking, challenges the current methodology for setting standards and labels. This methodology was originally developed for stand-alone products that have a single main function that does not change over time. However, especially electronic products have multiple functions. Chapter 7 (***A modular functional approach to product efficiency standards***) explores an alternative approach to setting MEPS in response to the challenge of multiple functions. It addresses the research question whether a function-oriented approach to setting standards instead of a product-oriented approach is possible and what the pros and cons are.

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[52] Following the failure of DOE to meet the deadlines under the Energy Policy Act of 2005 to deliver new or amended appliance standards, an analysis of the causes for the missed deadlines and the delays was undertaken (US DOE 2006).

2.

International benchmarking of products for policy makers[53]

Abstract

In the development of effective product efficiency policy, the critical element for policy makers is comprehensive, independent information. However, easily accessible, reliable information on the energy performance of products and policies is often scarce within a particular market, and rarer still if the policy maker is seeking comparisons on an international level. This article presents a method (Mapping & Benchmarking) to compare energy efficiency of products across countries, and the results for 3 products: refrigerators-freezers, washing machines and laundry driers. The results show an improvement of the efficiency over time for these products. However, part of this improvement is due to increased capacity of the products and not to lower energy consumption. Therefore policy makers should consider the development of policies based on product energy consumption and not (only) on product efficiency in order to capture the full potential of technology improvements for energy savings. Results for refrigerator-freezers suggest that in the long run both a policy strategy where minimum efficiency requirements are prominent and a policy strategy where a mandatory energy label is prominent can provide for increasing efficiencies.

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[53] Published as: Hans-Paul Siderius, Stuart Jeffcott and Kornelis Blok. 2012. International benchmarking: Supplying the information for product efficiency policy makers. Energy Policy 45: 389-398.

2.1. Introduction

Appliances account for a large share of electricity consumption (IEA 2003). Therefore product efficiency policy is an important part of energy policy to reduce CO_2 emissions, increase security of supply and fight energy poverty (Jollands et al. 2010). In the area of product efficiency policy, minimum efficiency standards and energy labelling are regarded as one of the most effective policies (Geller et al. 2006). The methodology for setting standards (and labelling classes) is well known (see Turiel et al. (1997) and Wiel and McMahon (2003)).

A critical element in both the development and monitoring of product efficiency policy is comprehensive data over time on energy consumption and energy related characteristics of products (Vine et al. 2010). Policy makers must ensure that the standards are ambitious enough to realize more savings than in a business as usual scenario but also feasible. Availability of data is even more crucial when evaluating product efficiency policy. In both cases – policy development and monitoring – international data, i.e. data from different countries or regions in the world, can be useful. Since ever more products are traded world wide, setting the standard at the level of the most efficient products can increase savings (Waide et al. 2010).

Energy efficiency indicators for comparison between countries (benchmarks) have been developed for industry, transport and buildings (see Schipper and Meyers 1992, Phylipsen et al. 1997) and are used in IEA publications (see IEA 2004 and IEA 2009). Energy performance maps have been produced for some products within specific countries, e.g. for refrigerator-freezers in the USA (see Battles and Hojjati 2005). Benchmarks of product performance are rare, although benchmarks of policies are more common, e.g. for electric motors (see Almeida et al. 2009). There are also some examples of benchmarks for the most efficient products within regions, e.g. Top Ten Best of Europe (www.topten.info), Top Ten USA (www.toptenusa.org) and an Asia-Pacific study on Air-Conditioners (APEC-ESIS 2004). However, easily accessible, reliable information on the energy performance per product over time is scarce and rarer still are data on comparisons on an international level. As we will show in this article one of the reasons might be that in most cases data are not directly comparable, i.e. data manipulation (normalisation) is needed before fair comparisons can be made. This not only holds for data but also for comparisons of product standards between countries. Therefore countries[54] participating in the IEA 4E (Efficient Electrical End-use Equipment) Implementing Agreement established the Mapping & Benchmarking (M&B) Annex in 2008. This Annex aims to provide policy makers with a single source knowledge base on product performance and associated policy tools employed by economies across the world, thus enabling more informed policy making at the national and regional levels and stimulating alignment to the most efficient policies world wide.

In this article we present a method to compare energy efficiency of products across countries and apply this method to 3 product groups. First we describe the processes employed to enable Mapping & Benchmarking and the benefits from the Mapping & Benchmarking approach for the countries participating in this collaborative approach. Secondly we provide some of the results for 3 product groups analysed by the Annex: domestic cold appliances, washing machines and laundry driers. Thirdly we show how these results can be used for policy development and evaluation. The article concludes with lessons learned regarding data collection and processing and some recommendations on products.

2.2. What is Mapping & Benchmarking?

2.2.1. Introduction; definitions

Mapping is the process of collecting data on energy consumption and energy related aspects of a single product or category of products over a number of years to show the development over time of energy consumption, energy efficiency and other energy related aspects of that product for a country or region[55]. This process results in one or more ‘maps’. Mapping can be applied to different aspects, e.g. the average stock of products, or the average, most or least efficient products available on the market.

Benchmarking is the process of analysing comparable data on energy consumption and energy related aspects of a product or category of products across various countries or regions in order to compare product performance, analyse variations and show best

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[54] Currently: Australia, Austria, Canada, Denmark, France, Japan, Korea, the Netherlands, South Africa, Sweden, Switzerland, UK and USA.

[55] A relevant region is the EU, because product efficiency policy to a large extent is set by the European Commission. In the maps and benchmarks the EU is treated as a ”country”.

practices. The results of this process are firstly data sets that can be fairly compared with each other, and secondly benchmarks on the various energy performance aspects to show how average, best and worst performance levels (for example) compare between countries.

Maps provide national policy makers with comprehensive information on the energy performance of a product locally, so that they can understand the trend and identify the range of efficiencies within the market. Benchmarks make the data between countries comparable, so that best practices can be shared and potential for further improvement of energy efficiency levels is highlighted.

2.2.2. Process of Mapping & Benchmarking

Mapping & Benchmarking is a collaborative process within the 4E Mapping & Benchmarking Annex, involving the direct participation of government officials and/or their experts in the work of the Annex. All participants are engaged and agree on the important decisions, regarding product definitions and normalisation. Furthermore, prior to publication of the final maps and benchmarks all participants have to agree on the map of their data and the benchmark based on that map.

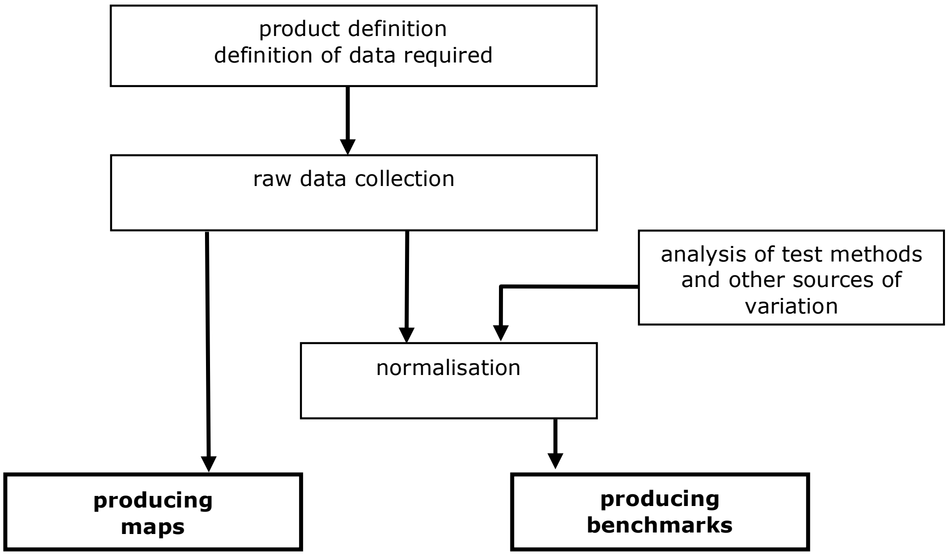

Figure 2.1 Steps of the mapping and benchmarking process

The following steps can be distinguished in the Mapping & Benchmarking process (4E M&B Annex 2009a); see **Figure 2.1**. These steps will be described in more detail in the rest of this section. However, before mapping and benchmarking can start, products or at least product categories need to be defined.

Product selection

Participating countries in the Mapping & Benchmarking Annex selected the following product categories to be addressed first: domestic cold appliances, televisions, domestic washing machines, domestic air conditioners, laptop computers, lighting and laundry driers. Criteria for the selection were significant level of electricity consumption and/or contribution to peak load and the likelihood of availability of sources of information. The selected products consume on average in the EU 36 % of household electricity consumption (Bertoldi and Atanasiu 2009, p. 13). In this article we concentrate on white goods: cold appliances, washing machines and laundry driers.

Product definition and definition of required data

For a given product, the first step in the process is the product definition. The product definition should be broad enough to encompass product variants in different parts of the world. Mainly this means that the product definition in principle will be based on functionality. However, a general product definition – e.g. a washing machine is an appliance for cleaning and rinsing of textiles using water – might be too general for product policy. Therefore products may need to be sub-categorized by functionality (beyond the main function), technology and size, capacity. In the 4E Annex a product sub-category selection process has been developed. In general it is favourable to keep the number of sub-categories limited. Data collection and processing efforts increase as the number of sub-categories increase. Also data on sub-categories might not be available, e.g. data for cold appliances often does not differentiate between some of the functionality. Furthermore, from an energy efficiency point of view, establishing or keeping sub-categories might result in a suboptimal situation if e.g. minimum efficiency standards per sub-category are set.

Regarding the required data, energy consumption and energy efficiency are central. Energy efficiency is the number of functional units of the product per unit of energy consumption. For white goods the functional unit is a unit volume of cool storage space (cold appliances), kg wash cleaned (washing machines) or dried (driers). The conventional metrics used for efficiency of white goods, kWh/unit volume or kWh/kg, are in fact the inverse of energy efficiency. Energy consumption will also need further qualification, e.g. energy consumption per day or year (cold appliances) or per cycle (washing machines, driers). Required data can typically be categorized as follows:

- Product data on energy consumption and energy related performance aspects (market information).
- Product data on other product aspects that affect energy performance (e.g. capacity).
- Product data that is used for product normalisation (e.g. climate class used for testing).
- Test methodologies used and their relationship to known international measurement methods in e.g. IEC or ISO standards.
- Information on policies directly influencing the energy efficiency of the product.

For mapping and benchmarking sales-weighted data, where each data of each product is weighted according to its sales, are preferred. However, sales data often are confidential and not available; in these cases product-weighted data, where each product has equal weight, is used.

Clearly this process is somewhat simplified and a number of challenges exist. First, given the divergence in product test methodologies and the less than ideal differentiation of product categorisation by country, often but not always driven by local cultural practice, products have evolved and are classified in different ways. Hence, defining the product sub-categorisations in such a way which allows the products groupings to produce meaningful results across the majority of participant countries can be difficult. Second, for the first products studied by the Annex, product definitions (both sub-categorisations and the definition of metrics and data requirements) were carried out based on knowledge of the local standards and classifications used within the participating countries. However, it rapidly became clear that this theoretical approach was inadequate as, although robust in itself, participant countries often did not have data available to match the definitions created. Thus, for later products, a two stage process has evolved where a draft definition and data requirement is created, followed by an investigation into data availability within participating countries. A re-analysis is then undertaken to establish how the product definition can be revised in line with data availability while still maintaining sufficient integrity in the following benchmarking to ensure results are useful and reliable.

Data collection and processing

The required data are sourced per product sub-category and country. To increase the ease of data processing and analysis, and to increase the reliability of the resulting output, original data sets are preferred, i.e. data sets with raw data per model. Other data sources used include analysis reports based on original data sets, commercial data or reports with meta-analysis.

The quality of the data can vary; therefore three quality levels have been defined to provide readers with an indication of how robust a given data set may be:

- Robust, where the data are largely representative of the full market, include at least a significant element of individual product data, are from known and reliable sources, and test methodologies are known and any data manipulations are based on solid evidence.
- Indicative, where data sets may not be fully representative of the market but do account for a majority, or any data manipulation includes some assumptions or unavoidable approximations that could reduce accuracy.
- Illustrative, where one or more significant parts of a data set is known to represent less than a majority of the full market, or test methodologies are not known or could lead to significant differences in outcome, or data manipulations contain an element of speculation or significant assumption or conflicting and equally valid evidence is available.

The quality of the data determines the quality of the conclusions that can be drawn from the data. Conclusions from robust data are reliable within the general boundaries indicated. Where data are indicative, meaningful but qualified conclusion can be drawn. Where data are illustrative, such data can still provide insight in the market situation and is worth reporting, but these results must be treated with caution. As would be expected of data from multiple sources, this definition of data quality can be challenging, in particular, understanding the composition of the data set and its representativeness of the market.

Data processing includes data manipulation to translate from the raw data format to the data format required for the analysis. For example, when data on energy consumption are only available expressed as an EU energy label class (e.g. ‘energy label B’), an assumption has to be made to translate the energy label class into an energy consumption value (kWh). While the actual processing of such transformations is conducted electronically, defining an accurate and reasonable set of transformations that maintain a level of integrity across the varying data sources is one of the most complex issues found. While product level data are preferred, many data are supplied at the market average level. This introduces a degree of uncertainty as any data manipulation that follows as part of the mapping or benchmarking process will inevitable increase the degree of error in the final results. The above also means that it is in general not possible to assign a numerical value regarding the accuracy to the data sets.

Producing maps

The collected and processed data now allow for producing maps. It is useful to have several maps per country to display different aspects. In the next section we will show some examples of maps produced by the Annex.

Normalisation; analysis of test methods

In comparing product performance across countries and regions, some allowance has to be made for variations that are due to the way in which data on energy performance was measured in each country. These include:

- Variation due to product performance aspects, e.g. climate class (temperature/humidity) at which the product is designed to operate;
- Variation due to environmental (test) conditions, e.g. different supply voltages or water inlet temperatures;
- Variation due to the use of different test methodologies between countries but also over time (changes/developments in test methodologies).

As a result of these variations the data from different countries and/or from different years cannot be directly compared in all cases. Therefore normalisation of data is necessary.

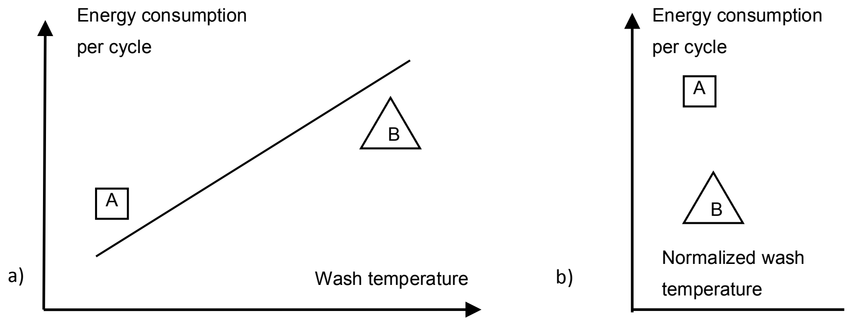

Figure 2.2 Effect of normalization (NB: not to scale - for illustration purpose only)

For example, **Figure 2.2** shows not normalised (a) and normalised (b) results for washing temperature versus energy consumption. Raw test results as in **Figure 2.2**(a) are simply not comparable as test temperatures are very different and so it is impossible to draw any conclusions on which region has the more efficient products. This comparison becomes possible if the results are normalised to a common level for each necessary parameter (such as wash temperature). Normalisation involves estimating what the energy result should be if both tests were to have been done at the same temperature, **Figure 2.2**(b).

Normalisation is done by applying factors, based on known and widely accepted factors, preferably based on physical laws or evidence. Where these factors were not available, expert opinion (including experts from industry) has been sought to propose factors. If no reliable factors could be found, data have been reported separately, i.e. benchmarking all participating countries against each other was not possible in a reasonably fair way for that aspect.

Producing benchmarks

The normalised data is used to produce benchmarks. In the next section we show some examples of benchmarks produced by the Annex. The quality of the benchmarks is determined by the quality of the underlying data sets and the robustness of the normalisation. Also for the benchmarks three quality levels have been defined:

- Robust, where the data sources being compared are largely ‘robust’ and no normalisation was necessary or if normalisation was necessary this was based upon solid evidence.
- Indicative, where data sets being compared are themselves only ‘indicative’, or any normalisation includes assumptions or unavoidable approximations that could unintentionally reduce accuracy.
- Illustrative, where one or more significant parts of the data sets are themselves ‘illustrative’, or any normalisation contains an element of speculation or significant assumption.

The consequences for the conclusions to be drawn are the same as indicated for mapping.

2.2.3. Benefits from the Mapping & Benchmarking approach followed

The Mapping & Benchmarking approach described in the foregoing section offers a structured framework for countries to collect and present efficiency data for products that are relevant for their product efficiency policy. The benefits of this approach fall in two categories: the benefits of Mapping & Benchmarking as such, and the benefits of a collaborative approach.

Regarding the first category it is clear that comprehensive information on the energy performance of products in the market is beneficial both to the evaluation and review of existing policies and to the design of new policies. For example, the EU’s ecodesign preparatory process of implementing measures asks for such data (see Annex II of the Ecodesign Directive[56] and (Kemna et al. 2005, p.18)). Not only data on their national market are useful, but also comparative information on the international level can bring energy efficiency forward. For example: the discussion on the ecodesign requirements for electric motors where the Commission invited US industry experts to the Consultation Forum to give a presentation on development of minimum efficiency standards. Within the Mapping & Benchmarking Annex these benefits are not only for participating

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[56] OJ L 285, 31.10.2009, p. 26.

governments, but also for a wider audience, e.g. industry, since in the end the (main) Mapping & Benchmarking results are placed on a publicly accessible website. This enables industry and other stakeholders, e.g. NGOs, to discuss policies on the same data basis.

The benefits of a collaborative approach are burden sharing and improved learning. Collaboration in the Annex reduces the cost per country and improves the quality. In principle the cost for Mapping & Benchmarking for one country is more or less the same as the cost for all countries, assuming that the benchmark is based on data from all countries. Various data sets used in the Mapping & Benchmarking process are only available because the government officials participate in the process. Furthermore, the structured, collaborative approach stimulates improved learning, e.g. awareness of key issues and ownership of results, through regular presentations and discussions of the (draft) results. Through input from experts from all over the world more input is provided to the process than when done by a single country on its own and decisions on e.g. conversion factors can be better substantiated. This wide collaboration also has an additional benefit in that a larger pool of policy makers/experts have a greater understanding of the challenges of non-harmonised test methods, product categorisation and non-aligned data capture practises, and hence increases the motivation to align such differences in the future.

The collaborative approach also has some disadvantages, mainly being the loss of flexibility for a single country to decide on the products to be analysed. Countries may have a different priority for some product based on their specific situation that is not matched by the average priority of the group. Another aspect is that the timing of the Mapping & Benchmarking process for each product will probably not coincide with the policy process in the different countries. However, since the standard setting process is in most cases a cyclic process, the results of Mapping & Benchmarking can be applied in future standards setting.

2.3. **Results**

This section provides results for the following products:

- cold appliances: refrigerator/freezer combinations and freezers only
- domestic washing machines (clothes washers)

- laundry driers (clothes driers)

For each product a short description of the product definition will be provided and information on the normalisation process is given. The emphasis will be on the benchmarking results; full results are available on the Annex website (http://mappingandbenchmarking.4E-iea.org/matrix).

2.3.1. Cold appliances

Product definition

For cold appliances, refrigerator-freezer combinations and freezer only units have been selected as relevant product categories for policy makers in the participating countries as they are the dominant products in almost all countries (i.e. stand alone refrigerators were not taken into account). The product categories have been considered based on functionality, i.e. they perform the same basic function of cooling or freezing in the relevant compartment contents. The following metrics have been defined:

- Unit Energy Consumption in kWh/year (total consumption, not corrected for volume or other parameters).
- Unit Energy Efficiency in kWh/litre,year (corrected for adjusted volume of individual compartments, no correction for other parameters).

Data processing and normalisation

Cold appliances are amongst the few products that have been subject to regulations (minimum efficiency standards and labels) for more than a decade in many economies. For most of the countries time series data of 10 years or more are available, either through government databases (Australia, Austria, Denmark, Canada, Korea, USA, and China), industry sources (Switzerland) or commercial sources (UK and EU).

For normalisation the following correction factors have been applied (4E M&B Annex 2010, p. 33-35):

- Correction factor for icemakers: the inclusion of an icemaker adds approximately 5% to the overall energy usage of the unit even when the icemaker is switched off (e.g.

due to increased heat ingress to the unit). Thus, to make such units comparable in to units without the icemaker, 5% was deducted from declared energy consumption.

- Adjusted Volume used to compare units with e.g. large refrigerators and smaller freezers with units with opposite configuration: Total Adjusted Volume = Declared Volume Fresh + 2.15 × Declared Volume Frozen.
- Adjustment for difference between internal and external temperatures according to various test methodologies: 3 % change in energy consumption per 1 ^{0}C change in difference between internal and external temperature. Normalisation was based on conversion of energy consumption to the EU differential test temperatures.

Benchmarking results

As examples of the benchmarking for cold appliances, **Figure 2.3** and **Figure 2.4** provide results refrigerator-freezer combinations. For both figures also Australian data for 1996-2000 were available. However, these data were not representative of the total market because larger refrigerators were (much) less represented, and are not included in **Figure 2.3** and **Figure 2.4**.

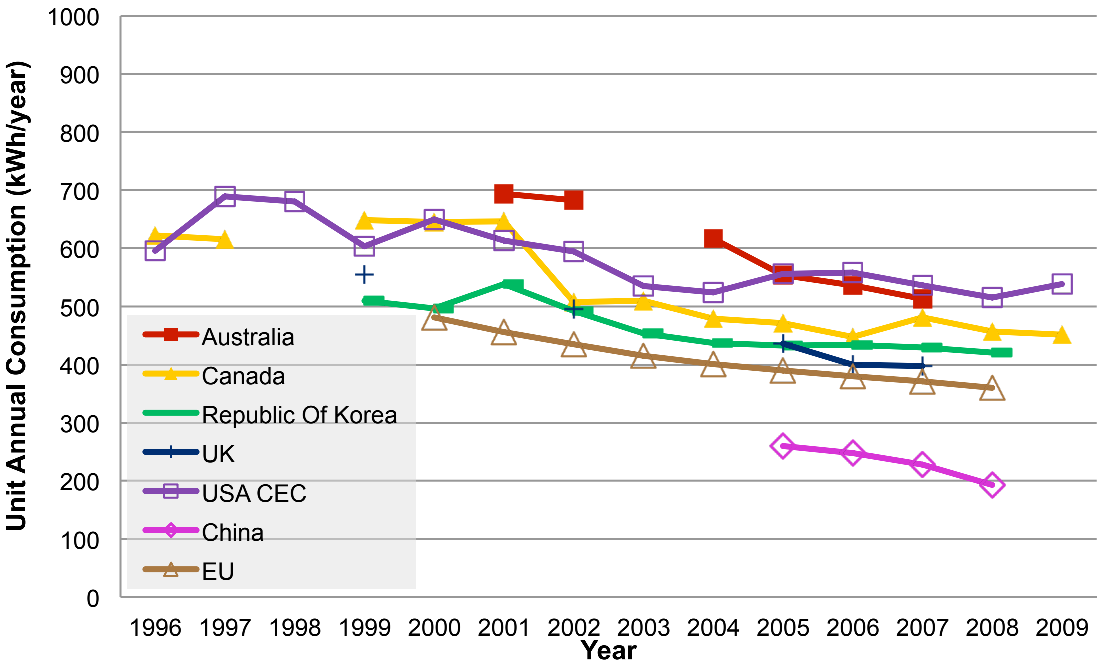

Figure 2.3 Refrigerator-freezers: indicative (USA: illustrative) normalised new product weighted annual energy consumption (kWh/year) (4E M&B Annex 2010, p.6)

The USA data in **Figure 2.3** and **Figure 2.4** are from a CEC (Californian Energy Commission; see http://www.appliances.energy.ca.gov/QuickSearch.aspx) data set, which became available after the Mapping&Benchmarking report on cold appliances had been published. It is the largest data set available from the USA suitable for normalization. Although it is representative for the USA it has legacy problems: products entering the market at a certain year may not have been removed from the data set when no longer available. Therefore this data can be considered illustrative only.

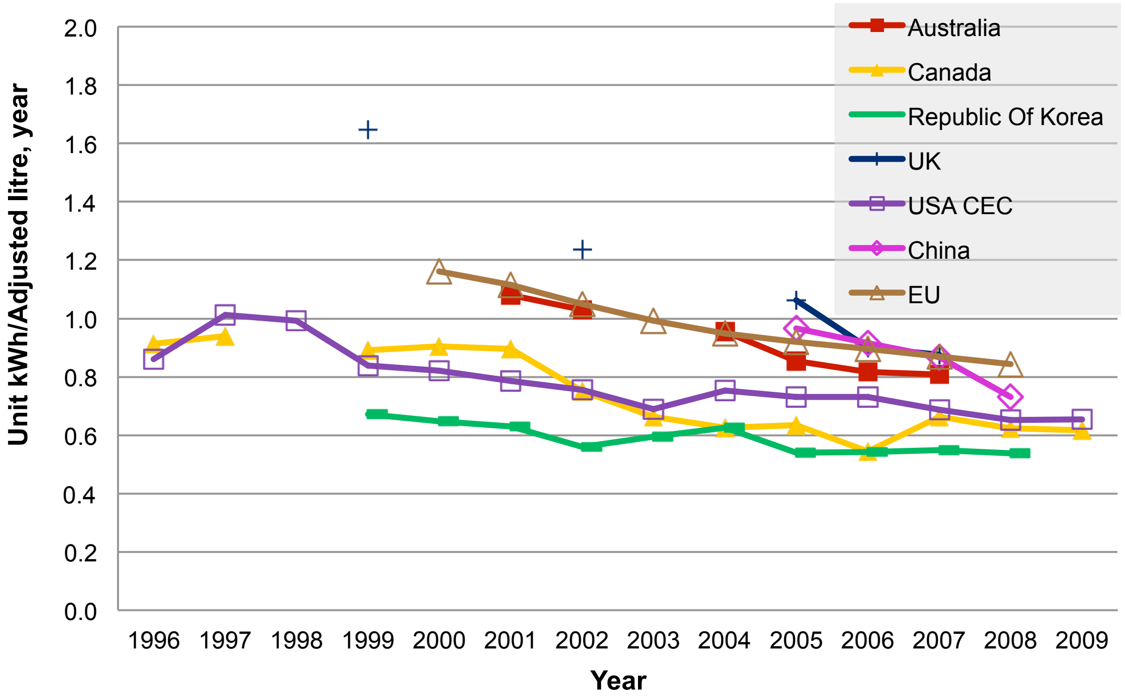

Figure 2.4 Refrigerator-freezers: illustrative normalised new product weighted (kWh/adjusted litre, year) (4E M&B Annex 2010, p. 41)

These benchmarks show that both annual energy consumption (kWh/year) and efficiency (kWh/adjusted litre,year) are improving over time. However, comparison of the figures also shows that efficiency is not always a good indicator of annual consumption: whereas in 2008 the efficiency of refrigerator-freezers in the EU is the worst, the annual consumption is amongst the lowest. The capacity (volume) of cold appliances is an important functional aspect and influences the energy consumption of the product. The volume of refrigerator-freezers has increased in most countries during the period 1999-2007 (Australia 22 %, Korea 13 %, UK 42 %) but more recent data suggest that volumes plateau. However, still the differences in absolute volume are large: on average the volume of the fresh compartment in Korea, Canada and USA is almost twice the volume in the EU (410 litres versus 210 litres) and more than 3 times the volume in China (120 litres). **Figure 2.5** shows the correlation between volume and energy consumption for new products (2007) in various countries with a best fit (power) line added. The differences in slope of the trend lines reflect differences in the markets of the various countries. While one would expect all lines to have a certain slope, i.e. showing increasing energy consumption with increasing volume, the Korean trend line is remarkably flat. This is because on one hand the products on the Korean market with a large volume have a relatively low energy consumption while the products with a small volume have a relatively high energy consumption. Apparently energy policy in Korea (4E M&B Annex 2010, p. 31) focussed on larger appliances.

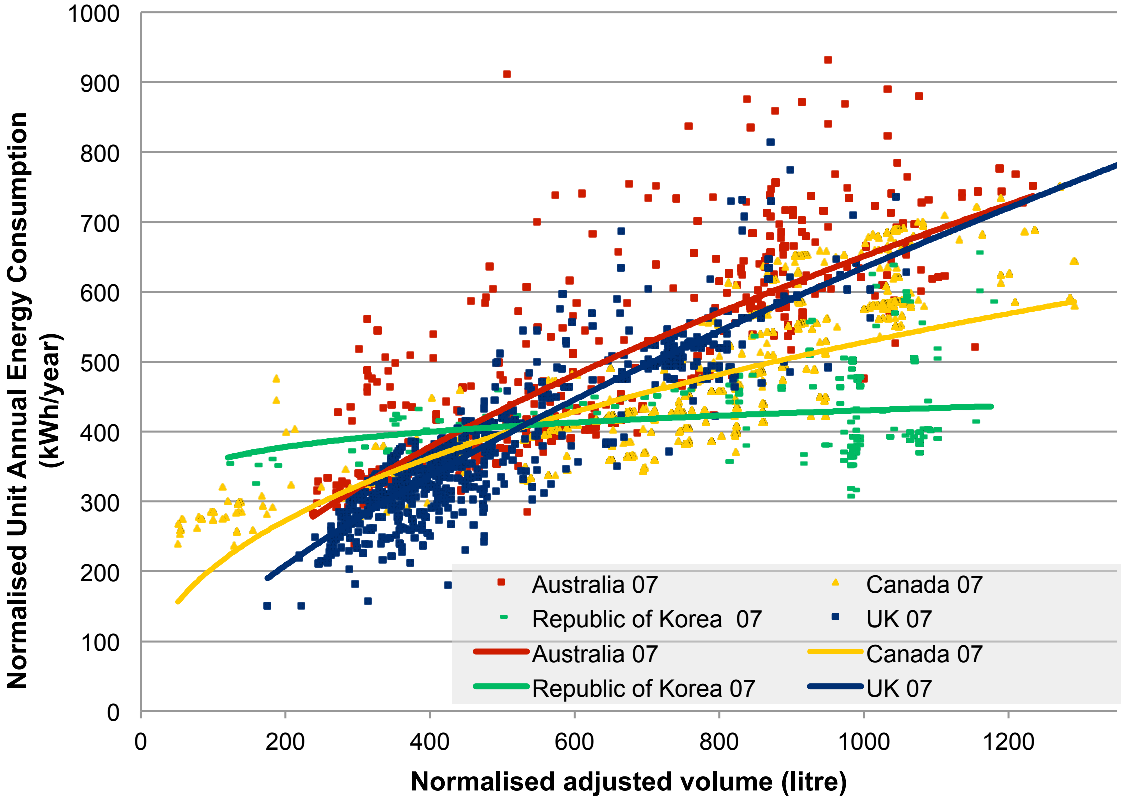

Figure 2.5 Refrigerator-freezers: robust comparison of energy consumption (kWh/year) of individual 2007 models by volume (litre) with a best fit (power) line added (4E M&B Annex 2010, p.57)

2.3.2. Washing machines

Product definition

For the Mapping & Benchmarking process a washing machine is “an appliance for cleaning and rinsing of textiles using water which is principally designed for use within a domestic environment. The appliance may draw water from a cold and/or hot water supply and may also have a means of extracting excess water from the textiles” (4E M&B Annex 2009, p.6).

In line with almost all testing methodologies and regulations worldwide, the energy consumed by a unit over one year was defined as Unit Energy Consumption: kWh/standard wash (unit consumption, not corrected for capacity or other variables). Energy efficiency was defined as Unit Energy Efficiency: kWh/kg (test cycle).

Data processing and normalisation

Data were acquired from several sources: governmental databases (Australia, Denmark, Canada, Korea, USA and China), industry sources (Switzerland) or commercial sources (UK, Austria and EU).

The two main differences between the testing methodologies (standards) lie in:

- The wash temperature and the water inlet temperature during the test which varies significantly between countries.
- The load (in kg) used for the test. In Canada and USA tests are carried out with a fixed load regardless the capacity of the machine, whereas in other countries the machine is tested with a load according to the rated capacity. However, Canadian and USA capacities were converted to kg equivalent based on the declared drum size of the unit and the identical drum capacity/kg equivalence tables published in their respective standards.

The normalisation step focussed on correcting for the wash temperature and the water inlet temperature that are used in the test (4E M&B Annex 2011b, p. 41-42). A fixed value of 0.15 kWh/cycle for mechanical energy (average based on Australian and UK test data) was deducted from the energy consumption for a cycle. The remainder was adjusted for difference in wash temperature by multiplying by

$$(T_{\text{wash normalised}} - T_{\text{inlet normalised}}) / (T_{\text{wash under test}} - T_{\text{inlet under test}})$$

where the normalised wash temperature is 40°C and the normalised inlet temperature is 15°C. It should be noted that this normalisation process is indicative as, given the none-compatibility of test methodologies, it has proved impossible to take account of differences in other variables which have direct impact on energy consumption, in particular wash quality, water hardness, detergent differences, etc. Further, in the case of Canada and the USA, the declared energy consumption of units is based on a combination of test temperatures/cycles the details of which are not declared for each individual unit. More important, the USA does not have a requirement (or measurement) for washing performance which allows for lowering the energy consumption by lowering washing performance without this being obvious.

Mapping & Benchmarking results

Regarding washing machines several cultural aspects influence energy consumption: especially this relates to wash temperature where in some countries cold wash prevails while in others warm or hot washes are the norm, but also to the spin speed and the use of top loaders versus front loaders.

For washing machines we start with a mapping result: **Figure 2.6** shows average normalised energy consumption (sales weighted) for the EU from a neutral, i.e. not a washing machine manufacturer, commercial source. The data supplied are restricted to products with greater than 0.1 % share of the sales, therefore the product with the highest and the lowest energy consumption may not represent the products with absolute lowest and highest efficiency on the market.

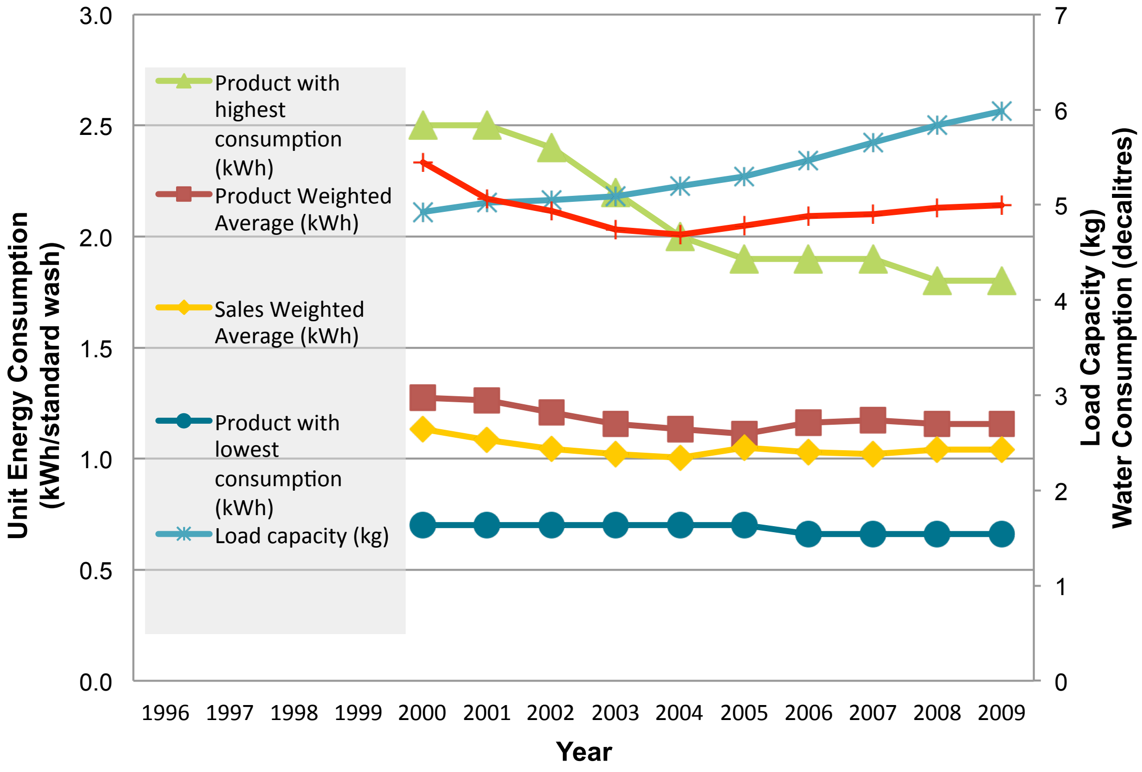

Figure 2.6 Washing machines: average normalised energy consumption (kWh/standard wash) for the EU (4E M&B Annex 2011a, p. 5)

Interesting to note is the trade-off between capacity and energy consumption that emerges from the EU data: the energy consumption of the average standard wash decreased from 2000 till 2005 by 0.035 kWh/year, whereas the average capacity increased by 0.077 kg/year in that period. From 2006 till 2009 however, the energy consumption of the average standard wash stayed the same, whereas the average capacity increased by 0.16 kg/year. As a result the improvement in kWh/kg decreased from on average 0.012 kWh/kg/year in the first period (2000-2005) to 0.006 kWh/kg/year in the second period (2006-2009). This means that the increase in capacity in the period 2006-2009 resulted in a slower increase in efficiency.

Figure 2.7 shows the sales-weighted normalised average kWh/kg for top loaders (TL) and front loaders (FL). The distinction between top loaders and front loaders is useful because in different countries different machines are dominant in the market (e.g. top loaders in Australia, front loaders in Europe) and to analyse the differences in energy consumption and efficiency.

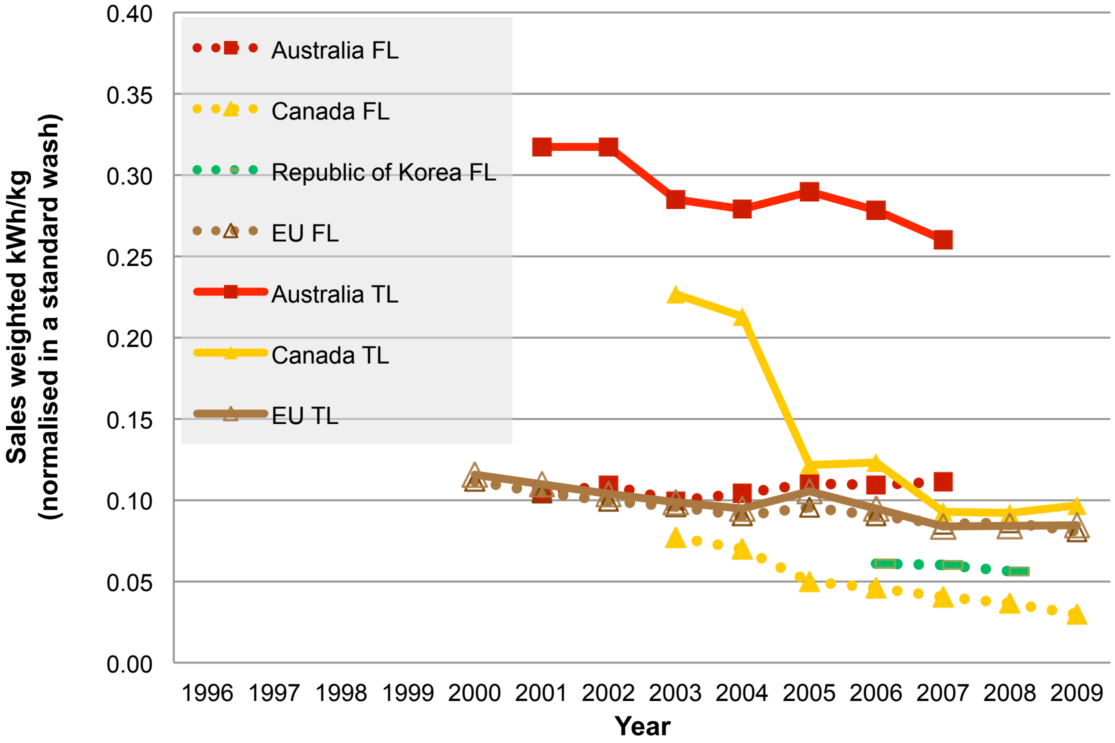

Figure 2.7 Washing machines: illustrative sales weighted normalised average kWh/kg for top loaders (TL) and front loaders (FL) (4E M&B Annex 2011b, p. 14-15)

Apart from showing that the efficiency levels of both top and front loaders for all situations (except top loaders in Australia) are below 0.10 kWh/kg, this figure also shows the limitations of the normalisation approach. We give two examples. Figures for Australian top loaders result from a conversion of a cold wash (20 ^{0}C) temperature (a correction factor of 5), whereas EU figures result from a conversion from 60 ^{0}C (a correction factor of 0.56). This means that violations in assumptions in the Australian data are amplified whereas for the EU data they are attenuated. Second, consumption data for Canadian machines are based on average machine consumption over a range of cycle conditions, however normalisation is based on this average unit consumption at the nominal wash temperature (57.2 ^{0}C) according to the standard. So, an actual lower wash temperature, e.g. 50 ^{0}C, will result in a lower consumption value which is normalised by a factor based on a higher nominal temperature resulting in an even lower consumption.

2.3.3. Laundry driers

Product definition

A laundry drier is an appliance designed to remove the moisture of a (given) load of textiles and in which textile material is dried by tumbling in a rotating drum, through which heated air is passed (EN61121: 2005). Although this seems a straightforward definition, it must be noted that it excludes driers without a rotating drum, e.g. cupboard driers which are in essence closets with a heating element and a ventilator, and are used in Scandinavia. This is an example where the general applicability of a product definition results in exclusion of a specific sub-category. Moreover cupboard driers do have other product characteristics, e.g. larger volume and much longer drying times (8 hours compared to 2 hours), which differentiate them from driers with a rotating drum.

The energy consumption of a drier is expressed in kWh/cycle, not corrected for capacity or other variables. However, as a basis for labelling and MEPS mostly energy efficiency is used, defined as Unit Energy Efficiency: kWh/kg (of dry fabric).

Data processing and normalisation

Data were obtained from several sources: (mandatory) government databases (Australia, Canada, Spain, USA), industry sources (DK, EU) and commercial sources (UK).

The main differences between the testing methodologies lie in:

- Ambient temperature and humidity.
- Textile load moisture content (initial and final).
- Fabric type.
- Weight of textile loaded into the drum.

For the first 3 factors data are normalised to the test conditions of the EU test methodology (EN61121: 2005) because the largest number of data sets submitted are tested to that standard. Regarding the weight of the load data are normalised to align with USA and Canadian methodologies which use a fixed textile load of 3.17 kg per cycle.

Table 2.1 summarizes the adjustments made during normalisation to energy consumption performance data.

Table 2.1 Normalised factors laundry driers (4E M&B Annex 2011c, p. 17, 47-57)

Country	**Ambient Temperature**	**Ambient Humidity**	**Textile Load**	**Moisture content**	**Fabric types**	**Total change (average)**
	(Vented driers)		*(Average* change)*			
Australia	-3.56%	0.75%	-31.2%	-29.2%	0%	-52.7%
Canada	1.04%	0.25%	0%	-8.2%	4.8%	-2.5%
EU	0.00%	0.00%	-36%	0%	0%	-35.5%
USA	1.04%	0.25%	0%	-8.2%	4.8%	-2.5%

* Actual magnitude of adjustments made for textile load varies according to the capacity of the appliance; figures show the average for that country.

Apart from the weight of the textile load the moisture content is the variable that has most influence on the normalisation. The factor for the moisture content includes two corrections: a correction for differences in initial moisture level (the moisture content of the textile load that goes into the drier) and a correction for differences in final moisture level (the moisture level of the textile load at the end of the drying cycle). Due to the significant differences in test methods comparison of results between USA/Canada and the other countries should be treated as illustrative.

Benchmarking results

Figure 2.8 shows the sales weighted (where available, otherwise product weighted) normalised kWh/kg of laundry driers. These data show a trend to converge at around 0.69-0.74 kWh/kg for 2009/2010. Furthermore, figure 8 suggests that the Swiss average has improved most: from being the worst in 2003 (0.85 kWh/kg) to become one of the best in 2009 (0.69 kWh/kg).

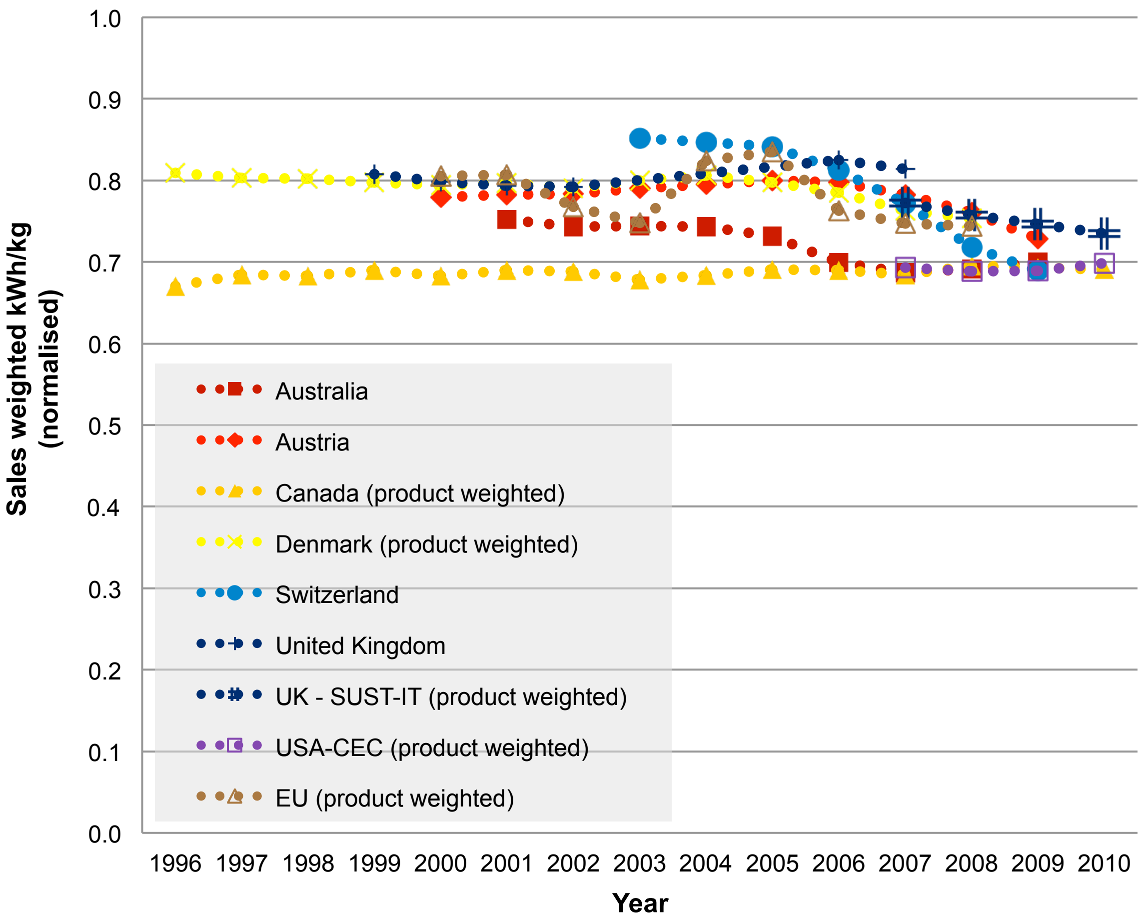

Figure 2.8 Laundry driers: average normalized energy consumption per kg (4E M&B Annex 2011c, p. 5)

Figure 2.9 provides some background on the current situation with the most recent available data for several countries. Although **Figure 2.8** suggests that the average efficiencies are converging, **Figure 2.9** show the individual product data behind the averages, including MEPS as set by Canada (since 1995), California and Switzerland (2012). Although data in **Figure 2.9** is illustrative (because of the normalization), it is clear that laundry driers with heat pump technology are around twice as efficient as laundry driers with resistive heating elements. The data sets for Denmark and Australia suggest a decrease in efficiency when the capacity increases, where according to physics one would expect an increase of efficiency. This is a market artefact: apparently energy efficiency has been less of a (design) issue for larger driers placed on the market in these countries.

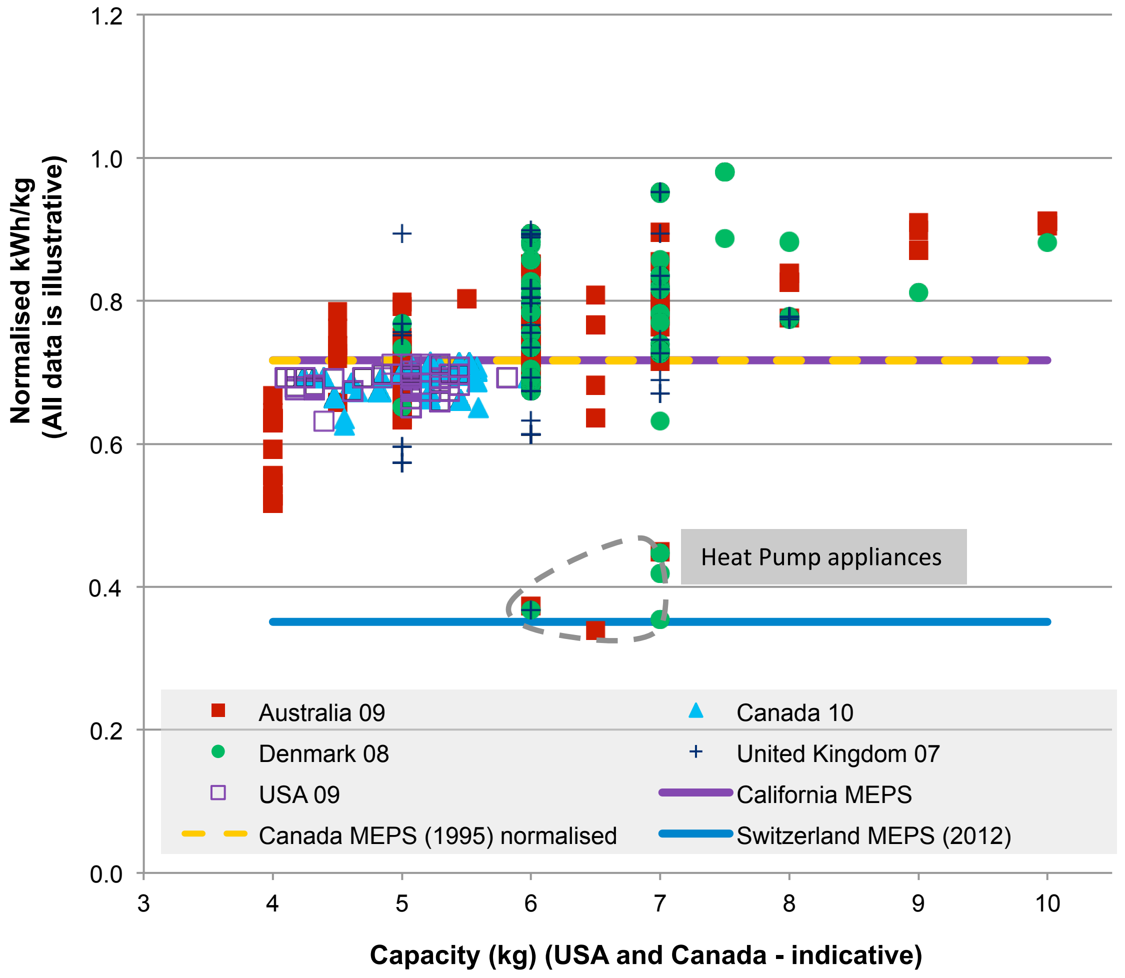

Figure 2.9 Laundry driers: scatter plot (individual product data) of normalized energy consumption per kg (4E M&B Annex 2011c, p. 6)

2.4. Using Mapping & Benchmarking: evaluation and policy development

In this section we provide some examples of the use of Mapping & Benchmarking for policy evaluation and development. Regarding policy evaluation we focus on cold appliances, which have the longest history of efficiency policies for appliances. Regarding policy development, we focus on the issue of capacity and on driers and we provide some general indication on technical potentials.

2.4.1. Policy evaluation: cold appliances

Ideally, the mapping results should show the impact of policies. In general the results presented in this article show an improvement of efficiency over time, which could be attributed to the policies in the countries. An alternative explanation could be the 'natural' efficiency development of appliances including a learning effect from subsequent development cycles and accumulating production volumes. Especially for cold appliances energy policies (minimum efficiency standards and energy labels) have been around for more than 20 years, therefore within the time series available it is not possible to estimate the efficiency improvements in a situation without any policy. Specific, in-depth policy research would be needed to establish cause-effect relations, if present.

However, for cold appliances the results in **Figure 2.3** and **Figure 2.4** reveal some interesting aspects regarding the policies in some countries. In Australia MEPS were introduced in 1999 and revised in 2005. However, the algorithm on which the (mandatory) labelling scheme is based was revised in 2000, and more important the data collection of the scheme was changed to include (more) larger appliances. Results for the product volume (4E M&B Annex 2010, p. 10) show a step change (increase) in volume. Therefore data before and after 2000 cannot be compared. However, **Figure 2.3** and **Figure 2.4** also show almost no impact from the revision of the MEPS in 2005, suggesting that this revision was probably more backing up efficiency improvements than initiating them.

In Canada MEPS were revised in 2001, resulting in a step change in annual energy consumption of products brought on the market in 2002 (see **Figure 2.3**). However, both **Figure 2.3** and **Figure 2.4** show little or no improvements before or after this change. This suggests that the other policy instruments in Canada, the (mandatory) EnergyGuide energy label, had little or no effect on the market.

In the EU there has been a continuous improvement in efficiency of cold appliances over the years (see **Figure 2.4**). The driver for this improvement has been the EU energy label; MEPS for cold appliances were introduced in 1999 and in 2002 the industry organisation CECED made a voluntary commitment to improve energy efficiency of cold appliances (CECED 2002). As with Australia the F**igure 2.3** and **Figure 2.4** do not show an (extra) impact from MEPS or the voluntary commitment; this is supported by data from the CECED database, see CECED (2002, p.28). However, with the introduction of the revised energy label (adding classes A+ and A++) in 2003 the improvement seems to have slowed down: compare the average yearly improvement of 0.054 kWh/year, adjusted litre in 2000-2004 with 0.027 kWh/year, adjusted litre in 2005-2008.

We see the following picture emerging from these cases. If there is a well functioning energy label (Australia, EU) the efficiency continuously improves over time and MEPS appear to have little influence on the efficiency (although they might prevent the market from going ‘backwards’). If the energy label does not function (well), MEPS seem to have a clear impact on the market, i.e. there is a step change in efficiency around the time when MEPS are introduced (or revised) but before and after the energy efficiency changes at a slower rate. Furthermore, from the Mapping & Benchmarking results no clear preference for either strategy – priority for MEPS or priority for energy labels – can be derived: over time the efficiencies for the various countries converge.

2.4.2. Policy development: capacity, driers and efficiency potential

For the 3 products discussed in this article (and others) capacity is both an important functional parameter and (thereby) directly influencing the efficiency. Efficiency increases with increase in capacity but this does not always translate in a proportionally lower energy consumption (see **Figure 2.6**). Therefore, if product efficiency policy wants to contribute to reduction of energy consumption and CO_2 emissions, the challenge is to increase the efficiency without increasing the capacity, or at least to increase the energy efficiency to such an extent that even with an increase in capacity the energy consumption is still reduced. In general, policy makers should consider the developments of policies based on energy consumption, or at least not on efficiency alone. That it is possible to set a cap on the yearly energy consumption of cold appliances is shown by **Figure 2.5**: for larger refrigerator-freezers (500-1100 litre) there is no reason to consume more than 400 kWh/year (normalised to local test conditions and based on 2007 market data) regardless of the volume. For lower sizes the consumption could decrease with the volume.

The results for driers point to a clear direction for policy development: stimulation of the uptake of heat pump driers. **Figure 2.9** clearly shows the differences in energy performance levels for MEPS for conventional driers (0.7 kWh/kg (normalised) in Canada and USA from 1995) and MEPS that can only be achieved by heat pump driers (0.35

kWh/kg (normalised) in Switzerland by 2012). The price difference between heat pump driers and conventional driers is large (about a factor 2 (Josephy et al. 2011, p. 1476)) which regarding the Ecodesign process in the EU resulted in not setting MEPS on this level for driers. **Figure 2.9** also reveals that the spread of efficiency of driers on the market is smaller in those countries that have MEPS (Canada, USA: 0.1 kWh/kg (normalised)) compared to countries without MEPS (Australia, Denmark en UK: 0.3 kWh/kg (normalised)). This further suggests that setting MEPS at the level of Canada and USA in the countries that currently do not have MEPS would decrease the average specific energy consumption for driers in these countries by 9 % (4E M&B Annex 2011c, p. 42).

The results from the Mapping & Benchmarking process also show the potential of adopting the best available efficiency products; see **Table 2.2** below for the EU. Compared to the current average of new products on the market efficiency improvements between 37 % (washing machines) and 64 % (driers) are possible with products already available on the market.

Table 2.2 Energy efficiency potential (EU data)

Product	Average efficiency new products	Best available efficiency
Refrigerator/freezer	0.84 kWh/l,year (2008)	0.42 kWh/l,year (2007)
Washing machine	1.04 kWh/kg,cycle (2009)	0.66 kWh/kg,cycle (2009)
Laundry drier	0.74 kWh/kg (2008)	0.27 kWh/kg (2008)

2.5. Conclusions and recommendations

In this article we presented a method (Mapping & Benchmarking) to compare energy efficiency of products across countries and presented results for 3 products: refrigerator-freezers, washing machines and laundry driers. Data from various regions of the world, notably USA/Canada, EU and Australia, were collected and processed, including review by experts and government officials participating in the IEA 4E Mapping & Benchmarking Annex. To enable fair comparison between data from different countries and/or different years normalisation was applied.

Policy lessons from the results

The results generally show an improvement in efficiency (kg/kWh for washing machines and driers, litre/kWh, year for refrigerator-freezers) over time for the 3 products. However, part of the efficiency improvement is due to an increase in capacity (kg dry wash, litres) and not due to lower energy consumption. The results therefore suggest that policy makers should consider the development of policies based on product energy consumption and not (only) on product efficiency in order to capture the full potential of technology improvements for energy savings. Results for refrigerator-freezers suggest that a maximum consumption of 400 kWh/year (normalised to local test conditions) for any volume above 500 litres is technically feasible whereas for lower sizes consumption could decrease with volume.

Results for refrigerator-freezers suggest that in the long run both a policy strategy where MEPS are prominent and a policy strategy where a mandatory energy label is prominent, can provide for increasing efficiencies.

Lessons learned regarding data collection, processing and normalisation

The following lessons were learned regarding the data collection and processing, thus providing recommendations for the Mapping & Benchmarking process:

- There is still a lack of readily available comprehensive time series data on energy efficiency of products. From the 10 countries participating in the Annex, data were available for at most 6 countries (cold appliances) plus the EU and China. And only in countries where there is an obligation to report to a government database (Australia, Canada, USA, Republic of Korea), are these data readily available.
- Model based data are the most easily and reliably manipulated data and allows for much more depth analysis than market aggregated data. Similarly, actual test data enable much more robust analysis rather than, for example, energy label classification which requires assumptions to be made about typical efficiency and performance within a classification.
- Data collection, cleaning and clarification is a time consuming task. Even if data are readily available it is mostly not available in the required format. This means that most raw data need to be converted to a consistent and compatible form.

- Caution has to be used when processing data, even when from the same source. Among other issues, when dealing with time series data it is important to check that the data are consistent in terms of market coverage and/or testing methodology and product classification.

Normalisation is in most cases possible and can yield useful results to show more fairly how the efficiency and energy consumption of the products/technologies compare between regions. Whilst usage patterns may vary by region and so require variation in test method, the challenges in normalising for example washing machine and drier test results imply that methodologies are fundamentally divergent, reflecting not only differences in usage patterns. One consequence of this is that energy efficiency, innovations or conversely poor product performance, in one region may not be evident and so could hamper transfer of best practice. Another risk from differences in test methodologies for similar products could be mistaken policy conclusions from comparison of performance. Using **Figure 2.2** as an example, one may be tempted to conclude that the wash cycle in country B results in less energy consumption than in country A. Normalisation results in a transformation relative to the normalization equation: the cycle in B uses less energy than the reference line, whereas the cycle in A uses more. What we can conclude is that if the products were tested at the same temperature, product A would consume more than product B. However, in absolute terms, the test cycle for A still uses less energy than the test cycle for B.

3.

Top Runner and Ecodesign[57]

Abstract

Both Top Runner in Japan and Ecodesign in the European Union are schemes to set requirements on the energy efficiency (MEPS: minimum efficiency performance standards) of a variety of products. This article provides an overview of the main characteristics and results of both schemes and gives recommendations for improving them. Both schemes contribute significantly to the energy efficiency targets set by the European Commission and the Japanese government. Although it is difficult to compare the absolute levels of the requirements, comparison of the relative improvements and of the savings on household electricity consumption (11 % in Japan, 16 % in the EU) suggest they are in the same range. Furthermore, the time needed to set or review requirements is in both schemes considerable (between 5 and 6 years on average) and the manageability increasingly will become a challenge.

The appeal of the Top Runner approach is that the most efficient product (Top Runner) sets the standard for all products at the next target year. Although the Ecodesign scheme includes the elements for a top runner approach, it could exploit this principle more explicitly. On the other hand the Top Runner scheme could benefit by using a real *minimum* efficiency performance standard instead of a fleet average. This would make the monitoring and enforcement more simple and transparent, and would open the scheme for products where the market situation is less clear.

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[57] Published as: Hans-Paul Siderius and Hidetoshi Nakagami. 2013. A MEPS is a MEPS is a MEPS: Comparing Ecodesign and Top Runner schemes for setting product efficiency standards. Energy Efficiency 6: 1-19.

3.1. Introduction

Product efficiency policy is an important part of energy policy and minimum efficiency standards are regarded as one of the most effective product efficiency policies (Geller et al. 2006). Every product efficiency standard policy has to find answers to the following questions (adapted from Turiel et al. (1997, p. 36)):

- Which products are in the scope?
- Where, at what level, to set the requirements (standards)?
- Which test methods are to be used?
- When to review and update the requirements?
- How to ensure that the requirements are met in practice (monitoring and enforcement)?

The answers to these questions not only concern the results but also deal with the process. In this article we will answer these questions for two major product efficiency standard schemes: the EU Ecodesign Directive and the Japanese Top Runner programme. Both schemes set energy efficiency requirements for products, albeit in a different way. The reason for comparing the Ecodesign and the Top Runner scheme is that the Top Runner scheme has appealed as a product efficiency standard policy to several countries in Europe (Germany (Jepsen et al. 2011), UK, the Netherlands) and the European Parliament (see e.g. Report A7-0219/2011 (European Parliament 2011)). Moreover, whereas the EU Ecodesign scheme is comparable to other product efficiency standards schemes in the world, e.g. US DOE standards (http://www1.eere.energy.gov/buildings/appliance_standards/) and the Australian MEPS programme (http://www.energyrating.com.au/meps1.html), the Japanese Top Runner programme has some unique features. This might indicate opportunities to learn from each other, other than fine tuning on aspects that are more or less the same.

Therefore, the aim of this article is to explore opportunities for improving the Ecodesign and the Top Runner scheme by analysing and comparing these schemes. The benefits of e.g. improving the Ecodesign scheme are large: tapping even a few percent more of the potential savings, would mean extra savings for the EU Ecodesign scheme in the order of

5-10 TWh/year in 2020. This is especially true for structural improvements in the scheme, i.e. improvements that are set as principles to be followed by all measures.

The article is organised as follows. First the main characteristics and results of the Top Runner and Ecodesign scheme are presented. Special attention is paid in trying to present the (expected) results of both schemes in such a way that they can be compared. Second, the article contrasts the differences between the two schemes, following the questions above. Finally we discuss the differences and similarities found in the analysis, draw conclusions and provide recommendations on how to improve both schemes.

3.2. Characteristics and results of the Top Runner programme

3.2.1. Main characteristics

In principle the Top Runner approach is simple. Assessing the energy consumption of products available on the market reveals the “Top Runner” product, i.e. the product with the highest energy efficiency. This product then sets the standard which all manufacturers have to meet for the (sales weighted) average of their products after a number of years (the target year). Then the cycle starts again with the assessment of the (new) Top Runner product.

The main characteristics of the Top Runner programme are (METI 2010, p. 6-7):

- The Top Runners set the standards.
- The standards setting process is dynamic, with stakeholder input.
- The standards refer to a fleet average.
- The standards are mandatory.

Besides these main characteristics the Top Runner programme has other aspects which are dealt with at the end of the section.

The Top Runner programme is part of the Japanese Law concerning the rational use of energy (Energy Conservation Law). Starting with 11 products in 1999 (Murakoshi et al. 1999), since 2009 the programme specifies standards for 23 products including means of transport, appliances, lighting, ICT equipment, heating and cooling equipment and transformers. To be eligible for the Top Runner programme a product must meet the following requirements (METI 2010, p. 11): the product is used in large quantities in Japan, the product consumes (in total) a considerable amount of energy while in use and there is potential to improve the energy efficiency.

The Top Runners set the standards

In principle the standard for the target year is set at the value of the most energy efficient product (the Top Runner) at the time of market analysis. Because the standard is based upon data from existing products it can be said that the standard is market driven, i.e. no standard is set that is not (yet) available in a product on the market. This is the general principle, however, standard setting takes into account technological innovation and diffusion and product price. The latter means that products with a high price will not be used to set the standard if the price difference, corrected for reductions due to larger production volumes, is not compensated for by lower running costs during the life time of the product. The standard should not be set by a unique product using patented technology; on the other hand if technological innovation indicates more room for improvement the standard can be set above the value of the Top Runner product as was done for DVD players.

Furthermore in setting the standards categorisation of products plays an important role, i.e. the standard value is not the same for a product but varies by category, e.g. DVD players with or without hard disk, or in relation to a main functional parameter, e.g. screen size for monitors (METI 2010, p. 13-16). Also specialty goods, e.g. custom made to order products in small quantities or products that use specific technologies with low market share (METI 2010, p. 18), are excluded when setting standard values for a category. It is explicitly indicated that target values for consumer electronics and office equipment should take into account reduction of standby power consumption.

A great advantage of this approach is that it is relatively easy to implement: the data is in most cases readily available and the analysis can be kept straightforward. Furthermore, no full life cycle cost analysis of design options is required (METI 2010, p. 6). However, the expected price of products is taken into account when setting the standards, as are costs for manufacturers when setting the target year taking into account product development cycles and investment for new production equipment.

The standards setting process is dynamic, with stakeholder input

The standards setting process is dynamic, i.e. the revision of the criteria is triggered when the target year for a product group approaches, or earlier when the criteria have been met well before the target year. The time span between setting the standards and the target year is between 3 and 11 years, with an average of 5.6 years (see Murakoshi et al. (2005, table 2)). The process of setting the standards takes up to 2.5 years, especially when measurement methods for energy consumption and/or performance have not been established (METI 2010, p. 12).

The standard setting process is organised through subcommittees of the Advisory Committee for Natural Resources and Energy, an advisory body for all energy conservation policies to the Minister of Economy, Trade and Industry. For the Top Runner programme the Energy Efficiency Standards Subcommittee was established. This subcommittee decides for which products Top Runner standards will be set and for each such product an Evaluation Standard Subcommittee is established. These subcommittees consist of representatives from various stakeholders: industry, academia, trade unions, consumer organisations. The Evaluation Standard Subcommittees prepare and discuss draft standards supported by specific working groups carrying out preparatory studies on e.g. measurement methods. Subcommittees and working groups are assisted and administered by the Energy Efficiency and Conservation Division of the Agency for Natural Resources and Energy. The meetings of the Evaluation Standards Subcommittees are partially closed to the public to preserve confidentiality of industry data. However, an interim report is made public on the internet and the subcommittee takes into account the comments when writing the final report. This report is sent to the Energy Efficiency Standards Subcommittee; after approval of this subcommittee the draft Top Runner standard for the product is established. English versions of (summaries of) these reports can be found on www.eccj.or.jp/top-runner/index.hmtl. The standard comes into force after authorization by the Advisory Committee for National Resources and Energy.

The standards refer to a fleet average

The fleet average of products, excluding exports, of a manufacturer shall comply with the standard. This means that the Top Runner approach is formally not a minimum efficiency performance standard: not all products of a manufacturer have to fulfil the target, but the sales weighted average has to. The fleet average provides flexibility for manufacturers, especially for products where several platforms co-exist and are sequentially updated as is the case for many consumer electronic and ICT products. Another advantage is that – in principle – no models are banned from the market. Even low efficiency products can be produced and sold, provided they are compensated for by the sales of high efficiency models.

The standards are mandatory

Mandatory standards can and should be enforced, otherwise they are in practice a voluntary agreement. As indicated in the previous paragraph the fleet average approach provides special challenges regarding enforcement. So far the Top Runner programme has been dominated by manufacturers and importers who are members of the respective industry associations, the majority of whom are Japanese. Enforcement within the Top Runner programme relies on ‘blame and shame’ by the government which works well in Japan with Japanese manufacturers and importers. It is uncertain how effective this type of enforcement is when non-Japanese or manufacturers with less known brands obtain a larger market share.

Other aspects

The Top Runner approach is complemented by related policy instruments, such as information to consumers, the use of Top Runner standards in public green procurement and award schemes and a tax reduction scheme for cars. Some of these instruments are mandatory, e.g. information provided by manufacturers, others are voluntary, e.g. the labelling scheme and the award scheme for retailers (Murakoshi et al. 2005). The labelling program covers 18 of the 23 products, notably exceptions are cars and vans. Since October 2006, for five products a “Uniform Energy Saving Label” is specified. Retailers have to display this label on or nearby the product in the shop.

Tojo (2005, p. 62) notes that especially the Green Procurement Law promoted earlier application of environmental technologies because the law came into force before the target years set for the Top Runner programme were reached.

3.2.2. Results of the Top Runner programme

Although information on sales-weighted averages is scarce, except for computers and cars, figures regarding the number of models placed on the market that comply with the Top Runner standards indicate that in general these standards have been met (Tojo 2005, p 40, 42).

Table 3.1 Percentage of products meeting the Top Runner standard

Product	**Target year**	**2000**	**2001**	**2002**	**2003**	**2004**
Desktop computers	2005	90 %	100 %	100 %	100 %	
Laptop computers	2005	88 %	89 %	100 %	100 %	
Cars	2005	37 %	55 %	73 %	80 %	87 %
Air conditioners	2004	40 %	57 %	59 %	90 %	100 %
Refrigerators	2004	47 %	77 %	82 %	87 %	96 %

Source: Tojo (2005, p. 40, 42)

METI (2010) summarizes results on improvements for all products; see **Table 3.2** for a summary overview and the Annex shows more details based on the reports approved by the Energy Efficiency Standards Subcommittee. Realized improvements are based on market data as supplied by manufacturers and importers for the reference year and the target year. Expected, targeted improvements are calculated based on data for the reference year and estimations of the average consumption of products shipped in the target year, assuming that products meet the target values. For example for refrigerators the sales weighted average energy consumption in 2005 is 572 kWh/year and the average energy consumption in 2010 is 542 kWh/year, assuming that the distribution of sales over the various categories will not change, resulting in an improvement of (572-452)/572 x 100% = 21%.

Table 3.2 Top Runner expected and realized improvements

Product	**First cycle**			**Second cycle**	
subcategories	***Reference year/Target year***	***Improvement [%]***		***Reference year/Target year***	***Improvement [%]***
		Expected	Realized		Expected
Airconditioners					
residential, cooling capacity ≤4kW, wall hung non-ducted	1997/2004	63	67.8	2005/2010	22.4
residential, cooling capacity >4kW, wall hung non-ducted				2006/2010	15.6
residential, other				2006/2012	15.6
commercial				2006/2015	18.2
Refrigerators	1998/2004	30.5	55.2	2005/2010	21
Freezers	1998/2004	22.9	29.6	2005/2010	12.7
Rice cookers	2003/2008	11.1	na	-	-
Microwave oven	2004/2008	8.5	na	-	-
Lighting					
fluorescent	1997/2005	16.6	35.7	2006/2012	7.7
bulb-shaped fluorescent				2006/2012	3.2
Toilet seats	2000/2006	10	14.6	2006/2012	9.7
TV Sets					
CRT	1997/2003	16.4	25.7	-	-
LCD	2004/2008	na	15.3	2008/2012	37
Plasma	2004/2008	na	15.3	2008/2012	37
VCRs	1997/2003	58.7	73.6	-	-
DVD recorders				-	-
non-DTB (digital terrestrial broadcasting) capable	2004/2008	na	22.4		
DTB (digital terrestrial broadcasting) capable	2006/2010	na	20.5		
Computers					
servers	2001/2007	69.2	80.8	2007/2011	62
personal computers	2001/2007			2007/2011	84
Magnetic Disc Units	2001/2007	71.4	85.7	2007/2011	76
Copying Machines	1997/2006	30.8	72.5	-	-
Space Heaters				-	-
Gas space heaters	2000/2006	na	1.4		
Oil space heaters	2000/2006	na	3.8		
Gas Cooking Appliances				-	-
Burner Section	2000/2006	na	13.9		
Grill Section	2002/2008	na	27.4		
Oven Section	2002/2008	na	20.3		
Gas Water Heaters				-	-
instantaneous and storage	2000/2006	na	4.1		
for space heating only	2002/2008	na	3.3		
combi: for space heating and hot water	2002/2008	na	1.1		
Oil Water Heaters	2000/2006	na	3.5	-	-
Vending Machines	2000/2005	33.9	37.3	2012	33.9
Transformers				2009/2014	12.5
Oil-filled	1999/2006	30.3	13.1		
Molded	1999/2007				
Routers	2006/2010	16.3		-	-
Switching Units	2006/2011	37.7		-	-

na: not available
Source: METI (2010)

At first instance these tables illustrate that the Top Runner approach is successful. However, since the targets have been (easily) met, it could also mean that the Top Runner standards were not strict enough. Tojo (2005, p 44) pays some attention on the relative stringency of the Top Runner standards, concluding that “manufacturers must be at least as well equipped with technologies as their counterparts abroad when it comes to meeting and exceeding the Top Runner standards”.

Estimates of energy savings, i.e. the avoided end-use energy consumption, resulting from Top Runner are scarce. Nordqvist (2006, p. 22) cites expected savings by 2010 of over 200 PJ for the residential and commercial sector and between 200 and 350 PJ for the transportation sector, but warns that these figures are unreliable, i.e. it is not clear what the baselines for the savings are. In total the savings contribute between one sixth to one fourth of the national energy efficiency savings target.

Based upon available data on household electricity consumption for 2009 (METI 2009) and the expected improvements in **Table 3.2** the following estimate of savings from Top Runner products on household electricity consumption can be made (see **Table 3.3**). Applying the expected improvement percentages of **Table 3.2** to the 2009 consumption of the respective Top Runner products results in savings for the situation where all products in the stock have been replaced by more efficient products according to the Top Runner standards. These savings are a conservative estimate because, although except for rice cookers and microwave ovens the target year is beyond 2009, already until 2009 products that are more efficient will have been sold and have therefore reduced the consumption in 2009. To obtain better estimates would require the use of bottom-up stock models.

Table 3.3 Expected savings from Top Runner products on household electricity consumption

Top Runner product	**Consumption 2009 (TWh/yr)**	**Savings (TWh/yr)**	**%**
Refrigerator-freezer	40.1	8.4	21
Lighting equipment	32.8	1.8	5
TV sets	21.8	8.1	37
Air conditioners	18.1	4.1	23
Electric toilet seats	7.6	0.7	9
Personal computers	6.1	2.6	43
Rice cookers	5.6	0.6	11
Microwave ovens	4.4	0.4	9
Routers	2.7	0.2	7
DVD recorders	2.2	0.2	9
Total	**141.4**	**27.1**	**19**

The Top Runner products account for almost 60 % of household electricity consumption (244.6 TWh in 2009). The savings amount to 19 % of the consumption of the Top Runner products and 11 % of total household electricity consumption.

3.3. Characteristics and results of the Ecodesign scheme

3.3.1. Main characteristics

As a consequence of the single market in the European Union, products are regulated at the EU level rather than the individual 27 Member States. The Ecodesign Directive 2009/125/EC of 21 October 2009 establishes a framework for setting requirements to relevant environmental characteristics of energy related products. Also the Directive contains selection criteria for the products for which requirements are to be set (Article 15(2)): significant volume of sales and trade (> 200 000 units per year in the EU), significant environmental impact and significant improvement potential. Working plans are established to select and prioritize the products for which requirements will be set. The Directive itself does not contain requirements for individual products; these are set in implementing measures (Regulations) or by self-regulation.

The main characteristics of the Ecodesign scheme are:

- Selection of aspects for which requirements are to be set by means of life cycle assessment.
- Setting of requirements is based on technical, environmental and economical analysis.
- Extensive stakeholder consultation.
- Enforcement is Member State responsibility.

For several product groups the Ecodesign requirements are complemented by other policies which are dealt with at the end of this section.

Selection of aspects for which requirements are to be set

Ecodesign not only deals with energy efficiency but with all relevant environmental aspects that can be significantly improved. Therefore a life cycle assessment is carried out to determine which are the relevant environmental aspects. Given that the products that have been subject to analysis so far are energy using products, i.e. products that are dependent upon energy input to work as intended, it is no surprise that emissions related to the energy consumption during use have been found to be the most relevant environmental aspect and all Ecodesign implementing measures published so far contain energy (efficiency) requirements. However, also water use (washing machines, dish washers), noise (air conditioners) and mercury (lamps) have been identified as relevant environmental aspects for which requirements have been set. Furthermore, requirements can be set for performance aspects to prevent that products are placed on the market that comply with the environmental requirements but have a poor performance. Examples are cleaning performance for dish washers and washing machines and lamp life time for lamps.

Setting of requirements based on technical, environmental and economical analysis

The methodology for setting specific Ecodesign requirements is provided in Annex II of the Directive, elaborated in more detail in Kemna et al. (2005); this methodology is used in all preparatory studies for Ecodesign implementing measures. The main part of this analysis runs as follows.

A technical, environmental and economic analysis will:

- select a number of representative variants of the product;
- identify the technical options for improving the environmental performance of the product (conditions: economic viability, no significant loss of performance or usefulness for consumers);
- identify, for the environmental aspects under consideration (i.e. energy efficiency) the best-performing products and technology available on the market;
- take into consideration the performance of products available on international markets and benchmarks set in other countries' legislation.

Concerning energy consumption in use, the level of energy efficiency or consumption will be set aiming at the life-cycle cost minimum to end-users for representative variants, taking into account the impact on other environmental aspects. Furthermore a sensitivity analysis covering the relevant factors will be carried out to check if there are significant changes and if the overall conclusions are reliable. Finally, the date of entry into force of the requirement will take the redesign cycle for the product into account.

Thus the analysis prescribed in the Ecodesign Directive takes into account the best performing products, legislation in other countries (i.e. outside the EU) and sets the target at the life-cycle cost minimum at a date taking into account the redesign cycle of the product. One way to accommodate for this is a tiered approach: requirements for the first tier, which mostly comes into force 1 year after the publication of the Regulation in the Official Journal, are modest whereas more stringent requirements come into force in the second tier, mostly 3 or 4 years after publication.

Annex VII, item 9 of the Ecodesign Directive requires implementing measures to state a date for the evaluation and possible revision of the implementing measure, taking into account the speed of technological progress. Also, almost all implementing measures published so far provide in an (indicative) Annex the benchmark values of the best performing products on the market.

Extensive stakeholder consultation

The process of setting Ecodesign requirements for a product is a three stage process. The first stage is a preparatory study which is carried out by consultants hired by the

European Commission. Stakeholder input is encouraged by sending out questionnaires and draft reports for comments and organizing stakeholder meetings. The study results in a report including policy options; however, these options are not binding for the Commission. The second stage starts with the Commission writing a working document that contains a proposal for an implementing measure including an explanatory note explaining the choices made or options given in the working document. This working document is discussed with stakeholders in the Consultation Forum. The first two stages are largely informal, i.e. apart from at least one meeting of the Consultation Forum (as requested in article 18 of the Directive) there is no formal procedure for these stages. The third stage can be considered the formal stage of the process. It starts when the Commission after successfully going through its internal review process (interservice consultation) sends a (final) proposal for an implementing measure to the members of the Regulatory Committee, consisting of EU Member States experts. The Committee discusses the proposal and can amend it. At the end of the meeting the proposal is voted upon. If adopted with a qualified majority, the text is then sent to the Council and the European Parliament for scrutiny. If both of them do not object, the implementing measure is adopted by the Commission and published in the Official Journal. The first and second stages are public, i.e. documents are available on public accessible websites and the meetings are open for all registered stakeholders, the third stage is restricted to Member State experts, Council members, members of the European Parliament and the Commission.

Due to – amongst others – the extensive stakeholder consultation the time between the start of the preparatory study and the coming into force of the first tier requirements is quite long. For the 12 implementing measures published so far the time span varies between 3.5 years and 6.7 years, with an average of almost 5 years. The time span from the start to the second tier varies between 5.25 years and 9.25 years with an average of almost 7 years.

Enforcement is Member State responsibility

The enforcement of the Ecodesign regulations is the responsibility of the EU Member States. In each Member State an enforcement authority has to be appointed that carries out activities to ensure that products comply with the requirements. Products that do not comply with the requirements can be withdrawn from the market by the enforcement authorities and the manufacturers of those products can be penalized. The Ecodesign Directive specifies in Article 20 that the penalties shall be “effective, proportionate and dissuasive, taking into account the extent of non-compliance and the number of units placed on the Community market.”

Member States are required by the Directive to cooperate with each other and the Commission regarding enforcements (Article 12). This is realized by the AdCo group where enforcement authorities of the Member States and the Commission meet twice a year and discuss enforcement strategies, plans and results.

Other policies for energy related products

For several product groups the Ecodesign requirements are complemented by other policies, e.g. the EU energy label, the EU ecolabel and the EU ENERGY STAR programme (see e.g. the Energy Efficiency Plan 2011 (European Commission 2011a)). Especially the energy label for a product is developed in the same process as the Ecodesign requirements, i.e. both share the same preparatory study. Furthermore, at the Member State level various other policies exist, which mainly relate to voluntary programmes for promoting higher efficiency appliances.

3.3.2. Results of the Ecodesign scheme

Although the Ecodesign directive itself came into force in 2005 and the first measures were published in 2008 and 2009, evaluation results are few (see e.g. CSES 2011). Notably exception is the Selina project that measured standby and off mode power consumption of around 6000 products in shops to check whether the products (already) complied to Regulation 2008/1025/EC on standby and off mode consumption (Almeida et al. 2011). They found that 81.5 % of the products complied with the off mode requirement and 69.0 % with the standby mode requirement even when measured in most cases before the requirements entered into force.

The results presented in this section are based on the preparatory studies and the impact assessments for the products (http://ec.europa.eu/energy/efficiency/ecodesign/legislation_en.htm).

Table 3.4 Savings potential Ecodesign (and Energy Labelling) implementing measures

	Final energy consumption (TWh/year)		
Product	**baseline**	**BAU 2020**	**Savings 2020**
Televisions[a]	60	132	43
Standby and off mode	47	49	35
External power supplies	17	31	9
Tertiary lighting	*200*	*260*	*38*
Air conditioners[a]	30	74	11
Electric motors	*1067*	*1252*	*135*
Circulators	50	55	23
Industrial fans	*344*	*560*	*34*
Cold appliances[a]	122	83	6
Washing machines[a]	35	38	2
Dishwashers[a]	25	34	2
Non-directional lighting[a]	112	135	39
Simple set-top box	6	14	9
Total	**2115**	**2716**	**386**

[a] Savings include effect of energy labelling according Directive 2010/30/EC.
Non-household products in *italics*.

The products for which an implementing measure has been published cover 30 % of the total primary energy consumption in the EU projected as Business As Usual (BAU) consumption in 2020. The measures are expected to result in a saving of 14 % of the BAU consumption in 2020 and result in a 22 % contribution to the 20 % energy efficiency target in 2020 of the European Union (European Commission 2011b). However note that water heaters and boilers are not listed in **Table 3.4**; from these products alone primary energy savings of 680 TWh/yr are expected according to the preparatory studies (Kemna et al. 2007a; Kemna et al. 2007b).

Table 3.5 Ecodesign requirements for products

Product	Regulation*	Energy consumption		Improvement Tier 2 vs Tier 1	Remarks
		Tier 1 *entry into force; requirement*	Tier 2 *entry into force; requirement*		
Televisions	EC/642/2009	20 Aug 2010 20 W + Ax4.3324 W/dm^2: on mode power consumption	1 Apr 2012 16 W + Ax3.4579 W/dm^2: on mode power consumption	20 %	A: visible screen area in dm^2.
Standby and off mode	EC/1275/2008	7 Jan 2010 Off: ≤ 1 W Standby: ≤ 1 W (2 W with display)	7 Jan 2013 Off: ≤ 0.5 W Standby: ≤ 0.5 W (1 W with display)	50 %	Tier 2 also includes power management requirement.
External power supplies	EC/278/2009	27 April 2010 0.5 W: no load	27 April 2011 0.3 W: no load	40 %	Additional requirements on average active efficiency based on a formula.
Tertiary lighting	EC/245/2009	Efficiency requirements in various yearly Tiers (1 Apr 2009 – 1 Apr 2017) for various categories of lamps, e.g. fluorescent lamps without ballast and high intensity discharge lamps. Furthermore the Regulation contains requirements for ballasts.			
Air conditioners	Adopted by Regulatory Committee but not yet published	1 Jan 2013 SEER ≥ 3.60 SCOP ≥ 3.40 Indoor sound power level ≤ 60 dB(A)	1 Jan 2014 SEER ≥ 4.60 SCOP ≥ 3.80	28 % 12 %	Requirements for air conditioners other than single duct and double duct with Global Warming Potential of refrigerant > 150 and capacity < 6 kW. For other requirements see Regulation.
Electric motors	EC/640/2009	16 Jun 2011 IE2	1 Jan 2015 IE3 or IE2 with variable speed drive	3.1 %	IEx: efficiency level as defined in Annex I of the regulation.
Circulators	EC/641/2009	1 Jan 2013 EEI<0.27	1 Aug 2015 EEI<0.23	15 %	EEI: energy efficiency index.
Industrial fans	EU/327/2011	1 Jan 2013 η_{target} varies with type of fan, power, efficiency category and measurement category	1 Jan 2015	17 %	
Cold appliances	EC/643/2009	1 Jul 2010 EEI<55	1 Jul 2013 EEI<44	20 %	Tier 3 (1 Jul 2014): EEI<42 EEI: energy efficiency index.
Washing machines	EU/1015/2010	1 Dec 2011 EEI<68	1 Dec 2013 EEI<59	13 %	EEI: energy efficiency index.
Dishwashers	EU/1016/2010	1 Dec 2011 EEI<71	1 Dec 2013 EEI<63	11 %	EEI: energy efficiency index.
Non-directional lighting	EC/244/2009	6 Tiers, with first 3 Tiers phasing out incandescent lighting: Tier 1 (1 Sep 2009): > 81 W, Tier 2 (1 Sep 2010): > 65 W, Tier 3 (1 Sep 2011): > 45 W. Wattages are approximations, values are stated in lumen in the Regulation. Furthermore requirements for non-clear lamps and functional requirements, e.g. lumen maintenance and starting time.			
Simple set-top box	EC/107/2009	25 Feb 2010 2 W: standby including display 8 W: on, including High Definition decoding	25 Feb 2012 1 W: standby, including display 6 W: on, including High Definition decoding	50 %: standby 25 %: on	

[a] Note that the format of the table only allows for the main requirements to be summarized; the full text of all regulations can be found on Eurlex: http://eur-lex.europa.eu/en/index.htm.

Savings for household products are 179 TWh/yr in 2020. However, these products are also partly used in the commercial, public and industrial sector, so not all savings can be attributed to households. A comparison with the data in Bertoldi and Atanasiu (2009, p. 13) suggests that 156 TWh/yr can be attributed to households. These savings are to be related to the BAU household electricity consumption in 2020. An estimate for this consumption can be made with the assumption provided by Capros et al. (2008, p. 50) that "Electricity consumption ... is projected to increase almost as fast as disposable income.", where the income in the residential sector increases with 2 % per year in the period 2005-2030. Since the residential electricity consumption in 2007 is 800 TWh/yr an increase of 25 % in the period 2008-2020 results in a consumption of 1000 TWh/yr in 2020. Thus savings of 156 TWh/yr amount to 16 % of total household electricity consumption.

Table 3.5 shows the expected improvements for the products for which an implementing measure has been published. Because of the complexity of the requirements an improvement percentage can not be provided for tertiary lighting and non-directional lighting.

3.4. Comparing Top Runner and Ecodesign

3.4.1. Scope of the scheme

Table 3.6 lists the products that are covered by the Top Runner programme and the products for which a preparatory study in the framework of the Ecodesign Directive has been or is carried out. Note that this table can only provide a global indication of the products covered by each of the schemes; even when the product groups names are identical the coverage will differ when looking at the exact definitions as specified in the implementing measures. From **Table 3.6** it can be concluded that the number of products covered by Ecodesign is larger than the number of products covered by Top Runner. For the products covered by Top Runner but not by Ecodesign there are two different explanations. First transport products are explicitly excluded from the Ecodesign scope (Article 1(3)); however other European regulations set efficiency and environmental requirements for e.g. cars (http://ec.europa.eu/enterprise/sectors/automotive/documents/directives/motor-vehicles/index_en.htm). Second electric toilet seats and electric rice cookers do not fulfil the criterium of significant volume of sales and trade to be eligible for a implementing measure under Ecodesign. For the products covered by Ecodesign but not by Top Runner, there are different explanations. First, several products have a small total energy consumption in Japan (e.g. dishwashers, washing machines, coffee machines). Second, for electric motors and products with an electric motor, e.g. circulators and pumps, stimulating the use of inverter control was more important than setting targets for the efficiency of the motor.

Table 3.6 Overview of products covered by the Top Runner programme and Ecodesign

Products covered by Top Runner	**and by Ecodesign**
Space heaters	Boilers, including combi-boilers
Water heaters	Water heaters
Computers, magnetic disc units	PCs and computer monitors
Copying machines	Copiers, faxes, printers, scanners, multifunctional devices (imaging equipment)
TV sets	Televisions
Air conditioners	Air conditioning appliances and systems, ventilation systems (domestic and commercial)
Refrigerators and freezers	Domestic refrigerators and freezers
Lighting equipment	Domestic lighting, Office lighting, Street lighting
Transformers	Transformers
VCRs, DVD recorders	AV equipment
Gas cooking appliances, microwave ovens	Domestic and commercial ovens, hobs and grills
Vending machines	Chillers, display cabinets and vending machines
	Products covered by Ecodesign (and not by Top Runner)
	Standby- and off-mode losses[b], network standby
	Battery chargers and external power supplies
	Electric motors
	Electric pumps, circulators
	Fans
	Domestic dishwashers and washing machines
	Solid fuel boilers
	Laundry driers
	Industrial air compressors
	Set-top boxes
	Vacuum cleaners
	Coffee machines
	Domestic Uninterruptable power supplies
	Commercial refrigerating and freezing equipment
	Industrial and laboratory furnaces and ovens
	Machine tools
Products covered by Top Runner	**(and not by Ecodesign)**
Electric toilet seats	
Electric rice cookers	
Passenger vehicles	
Freight vehicles	
Routers, switches[c]	

[a] Products for which an preparatory study has been or is carried out

[b] For the Top Runner scheme standby is included in consumer electronics and office equipment.

[c] Ecodesign will include these products in requirements for network standby

However electric motors are now under consideration for the Top Runner programme. Third, for other product groups, mainly in the commercial and industrial sector setting standards is considered too complex because of product diversity and/or lack of measurement methods.

Both schemes play an important role in meeting the energy efficiency targets as set by the European Union and Japan.

3.4.2. Where to set the requirements?

The difference between the Top Runner and Ecodesign approach on setting requirements is indicated by **Figure 3.1**. The start of the axis is the efficiency at the time of setting the requirements.

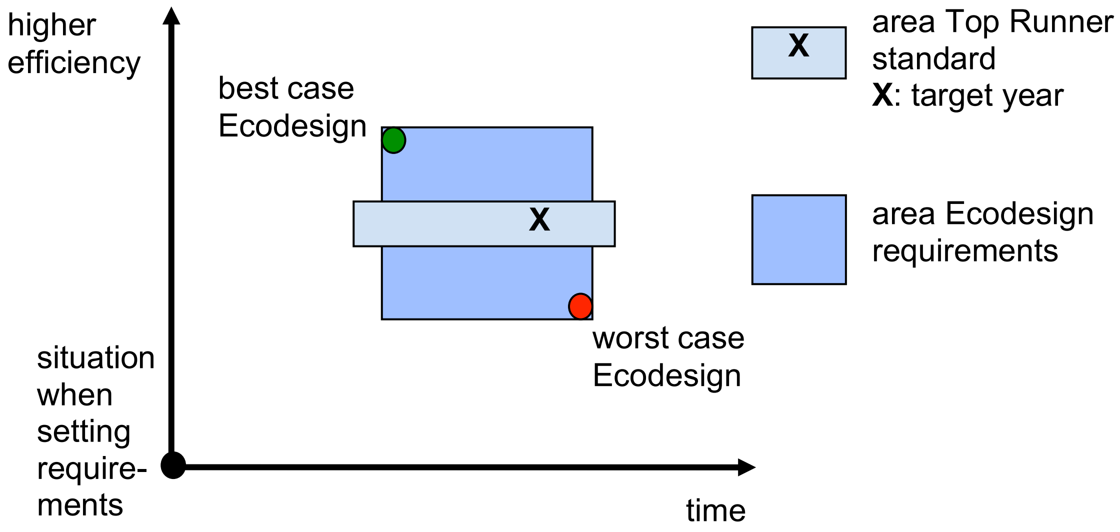

Figure 3.1 Standards setting: Top Runner versus Ecodesign

The difference between Top Runner and Ecodesign is that the standard setting in Ecodesign varies on both efficiency and time, whereas for the Top Runner scheme the efficiency level is – in principle – fixed by the Top Runner product. The Ecodesign Directive specifies explicitly the factors that influence standard setting, including the date of entry into force. Since these factors can vary, the result can be pictured as an area in the time-efficiency diagram as shown in **Figure 3.1**. This means that the (exact) point of the Ecodesign standard is not known beforehand. It can vary from the 'best case' (standard with a high efficiency level on short time) to the 'worst case' (standard with low efficiency level later on). In general Ecodesign requirements tend to be relaxed during the process, i.e. they move in **Figure 3.1** from the top left hand area (proposal in preparatory study) in the direction of the bottom right hand (values and timing in regulation).

For the Top Runner scheme the flexibility is in principle limited to the timing of the target year, which is set 3 to 10 years ahead. However the level of the standard can be moderated by the potential of technological innovation, patented technology to achieve the standard and high price of the Top Runner product. The Top Runner scheme is explicitly focussed on the Top Runner product to set the standard. However, the Ecodesign scheme takes into account best-performing products and benchmarks set in other countries legislation.

It is not possible to directly compare the absolute levels of the requirements between Top Runner (**Table 3.2**) and Ecodesign (**Table 3.4**) because the requirements are based on different definitions and measurements methods. **Table 3.7** compares the relative improvements for products for which both Ecodesign and Top Runner requirements exist.

Table 3.7 Relative improvements for Ecodesign and Top Runner

Product	**Improvement per year**[a]		**Remarks**
	Ecodesign	***Top Runner***	
Televisions	7.8 %	9.3 %	
Air conditioners	10 %	3.9 %	Ecodesign is average of SEER and SCOP improvements Top Runner is average for residential air conditioners
Refrigerators	4.7 %	4.2 %	Ecodesign does not differentiate between refrigerators and freezers
Freezers		2.5 %	

[a] Top Runner: total improvement second cycle / (target year – reference year); Ecodesign: improvement between Tier 1 and last Tier / period between regulation coming into force and last Tier coming into force.

Besides the general principles as indicated above there are other aspects when deciding upon the new target:

- Interference with other environmental aspects.
- Interference with performance aspects.
- Differentiation between products from the same category.

- Dealing with increased performance.

Decreasing energy consumption could interfere with improving other environmental aspects. Even if it is not directly conflicting, a strong focus on energy efficiency could absorb resources at manufacturers' that otherwise could have been used to improve other environmental aspects. Tojo (2005, p. 64) indicates some issues regarding expanding the Top Runner programme towards other environmental aspects, especially setting the boundary and agreeing on parameters would not be straightforward. Regarding Ecodesign interference of energy efficiency with other environmental aspects has only been an issue for noise, where for dishwashers and air conditioners it was argued by industry that stringent noise requirements would hamper (cost effective) energy efficiency improvements. First this is a result of Ecodesign being focussed on energy using products where the emissions related to the energy consumption in the use phase are the most important environmental aspect. Second there is other legislation in the EU (WEEE (Directive 2002/96/EC) and ROHS (Directive 2011/65/EU)) that deals with other environmental aspects of products. However, especially environmental NGOs have argued that Ecodesign implementing measures should pay (more) attention to these aspects.

Decreasing energy consumption could interfere with performance. Decreasing washing temperature could decrease the wash performance of a washing machine or dishwasher. A longer wash cycle in a washing machine to maintain performance at decreased temperature could increase wear of the fabric. Therefore Ecodesign implementing measures contain requirements for important performance aspects. Top Runner standards do not include such requirements but rely on measurement standards for these aspects.

Another aspect is the differentiation between products from the same category but with a different type of performance, e.g. a television with a small screen compared to one with a large screen or a refrigerator with and without internet terminal. Differentiating the standards with regard to such performance aspects ensures that a wide range of products are available because there is no penalty for e.g. a larger screens as such, but may result in increasing (absolute) energy consumption when consumers favour the larger products. Both the Top Runner and the Ecodesign scheme vary requirements according to performance, i.e. they set energy efficiency requirements. For some products, e.g. refrigerators, industrial fans and lighting, requirements are differentiated by technology. In general this is to be avoided since it will keep on the market technologies that are less efficient. However, the main reason for differentiated requirements is a specific technology sometimes offers other important benefits. For example absorption type refrigerators that are much less efficient than compressor type refrigerators but offer noiseless operation. Both Ecodesign and Top Runner programme accommodate for this by allowing setting different standards for different categories.

Performance of products is changing constantly, both quantitative (e.g. a larger screen or larger storage volume) and qualitative (new or improved features, e.g. high definition, network capability). Regarding quantitative developments, both Ecodesign and Top Runner as indicated set energy efficiency requirements that take variation of performance into account. However, if the performance of the product increases dramatically during the period, the standard looses its guiding principle. Examples in the Top Runner programme include standards for hard disks and computers where the requirements are formulated in Watt per operations per second and Watt per memory capacity respectively. The emergence of new features with impact on energy consumption poses a challenge for setting requirements. In general both Top Runner and Ecodesign provide allowances for (new) features, e.g. the allowance for High Definition encoding in the set top box regulation and for multiple tuners in the Top Runner television standard. Alternatives for allowances are switching off the features during the measurement of the power consumption if possible (see e.g. IEC 62087 for measuring energy consumption of televisions), exempt products with new features from the requirements or provide no allowances at all. This aspect is especially challenging for requirements on ICT and consumer electronics products. It also means for the Top Runner approach that the Top Runner product at a certain point in time does not automatically set the standard for the next target year because it does not have (all) the features that products in the target year will have.

Concluding, while it is not possible to directly compare the absolute levels of the requirements between Top Runner and Ecodesign, the relative improvements are in the same range. Although in practice the setting of requirements encounters the same issues in both processes and finds solutions that provide more or less the same results, the Top Runner approach has the large conceptual advantage that the aim is clear from the start: the Top Runner product sets – in principle – the new standard.

3.4.3. Which test methods are to be used?

Both Ecodesign and Top Runner prefer test methods established in harmonized (international) standards. However such standards might not be available for all products, or the existing standards are outdated or not complete. For both schemes the possibility exists when a harmonized standard is not available or not complete, to specify (additional) measurement methods, including measurement conditions, in the measure. For Top Runner such a method should be objective and quantitative. For Ecodesign, the Commission will specify a mandate to the European Standardization bodies to adopt the missing standards or amend existing standards to suit the needs of the implementing measure.

3.4.4. When to update the requirements?

Both Top Runner and Ecodesign have clear indications on when to update the requirements. For Top Runner this is (at least) the target year, whereas for Ecodesign each individual regulation specifies when the Commission will present a review to the Consultation Forum. Most Ecodesign regulations have a two or even multi tier approach. In most cases the review is planned after the last tier has come into force. However for some products (lighting, electric motors and dishwashers) the review will be carried out before the last tier comes into force. The reason is that at the time of setting the requirements it was not completely certain whether especially small and medium size enterprises could achieve the requirements on time. Although the review aims at updating the requirements for both Top Runner and Ecodesign, an update will only occur if there is still (substantial) improvement potential.

Table 3.8 compares the dynamics of updating between Top Runner and Ecodesign. Note that the figure for Top Runner has been calculated from actual updates whereas the figure for Ecodesign is based upon revisions to come.

Table 3.8 Time span (years) between two subsequent requirements for Ecodesign and Top Runner

	Average	Min	Max	Remarks
Ecodesign (n=12)	4.9	3.0	7.3	For 4 products the review will be before the last tier comes into force.
Top Runner (n=13)	6.0	3.0	8.0	For 13 of the 23 products requirements have been updated. For computers and magnetic disc units equirements have been updated twice.

3.4.5. Monitoring and enforcement

The Top Runner scheme requires manufacturers (and importers) to provide both energy (efficiency) and sales data for all products covered by the scheme at the target year. Because the fleet average needs to comply with the target, data from individual products cannot be conclusive regarding whether a manufacturer complies with the target for a certain product category. This means that the Top Runner scheme regarding monitoring and enforcement is highly dependent on co-operation from manufacturers and on confidential data. In practice this means that independent enforcement is not possible. Furthermore it requires a stable market situation in which manufacturers or importers do not change quickly. Second, it means that consumer purchasing behaviour is still important. Whereas with MEPS you can be sure that every product meets the standard, the fleet average approach goes wrong if too many customers buy products with low efficiency, which are then not compensated for by products bought with a high efficiency.

For the Ecodesign scheme independent enforcement is possible: every product shall meet the requirements. Every Ecodesign regulation contains an Annex on how to carry out enforcement activities, including the procedure how to decide whether a product complies or not. The challenges for enforcement lie in the fact that enforcement is a responsibility of each EU Member State individually; there is e.g. no European enforcement authority. Since there is no requirement for manufacturers or importers to register products or to send product data to the authorities, it depends on the activities of individual enforcement authorities in Member States to check whether products comply with the requirements. In practice these activities have a small scale or are even non-existent in several Member States (CSES 2011).

3.5. **Discussion**

One of the aims of this article is to investigate what the Top Runner and Ecodesign scheme could learn from each other, especially in the light of interest in Europe for the Top Runner scheme.

First, what this article shows is that both schemes have more in common than is sometimes suggested; this especially holds for the dynamic aspect where Top Runner is perceived as being continuously updated (e.g. Nordqvist (2006, p. 5)) and Ecodesign as being slow (Spengler and Jepsen 2010, p. 4). However, both Top Runner and Ecodesign are dynamic (tiered approach and/or updates) and the time needed to set or review requirements is in both schemes considerable and highly comparable. Although it is difficult to compare the absolute levels of the requirements, comparison of the relative improvements and of the savings on household electricity consumption suggest they are in the same range.

The common aspects suggest that the schemes could learn and benefit more from each other when they would be more harmonized. Harmonization of criteria and measurement methods would make it possible to compare the requirements and the results which could drive the ambitions of both schemes. Products where this harmonization is most easily realized are those that are produced and sold for a worldwide market and already have a single accepted measurement method, e.g. televisions.

Second, both schemes face some of the same limitations, which stem primarily from the condition that setting requirements is determined by the efficiency of the products on the market when setting the requirements, albeit that this can be the most efficient products. This means that for both schemes it is difficult to “force” innovations. Related to this is the condition that the market must be competitive enough to prevent manufacturers from concerted action to slow down efficiency improvements. Also, both schemes have difficulties in dealing with new or improved features and variations in functionality (Kimura 2010). A consequence is that an automatic update of making requirements more stringent is hardly possible for many products unless the claim of extra energy consumption by new or improved product features is denied.

Third, for both schemes the manageability increasingly will become a challenge. Several factors contribute. First the number of products (23 for Top Runner, 13 for Ecodesign with around 15 to come), second the success of the schemes combined with the intensive preparation and stakeholder consultation and third the type of products targeted. Although not all standards will be revised, e.g. the Top Runner standard for VCRs, with an average time span for updating of around 5 years, this means that in the years to come every year 4 to 5 products need to be revised. The familiarity with and success of the schemes result in more stakeholders more intensively participating in the process, which is as such a good thing but makes the management of the scheme more complex and time consuming. Revision of standards on one hand might be easier and quicker because it ‘only’ requires an update of the work already done, on the other hand for several products functionality, technology and/or the market may have changed dramatically so that in fact the preparations have to start from scratch. Regarding the type of products, especially expanding the scheme will create challenges. Both schemes have in the beginning dealt with relatively simple products, i.e. products for which measurement methods were available, which were already subject to other legislation (e.g. energy labelling in the EU) and for which the market was well organized.

Unfortunately there is no quick fix for the manageability challenge. Freeing more resources (money, persons) for the scheme is an obvious solution but might be politically less acceptable or realizable. The Ecodesign scheme allows for self-regulation instead of implementing measures; although this might decrease the workload for the administrators, the workload for industry is more or less the same. Furthermore self-regulation is in many cases not suitable or desired by industry, because self-regulation will not cover all market players (the three self-regulatory initiatives so far cover between 75 % and 98 % of their market). Improvements can be made regarding the planning of the process, e.g. the Ecodesign process is notorious for the delays in delivering the implementing measures, but this will probably only provide a small relief. Another suggestion would be to have more horizontal requirements, like for (network) standby in Ecodesign resulting in one regulation covering a large number of products, or to restrict the requirements to the most important products, i.e. to raise the eligibility criteria.

Although the differences between Top Runner and Ecodesign are more gradual than black and white, for each of the schemes there is at least one point where each of the schemes can learn from the other. For the Ecodesign scheme this is the principle that the Top Runner product sets the next requirements. The ingredients for applying this principle are already in the current scheme: the (indicative) benchmark values and the date of review. To apply the principle would mean that when reviewing the regulations the benchmark values in the existing regulation would be checked against the actual market situation and then be set as the basis for the revised regulation. As indicated above, unlike Top Runner, Ecodesign explicitly refers to the point of least life cycle costs (LLCC) to set specific requirements. However, since this point moves in time (the longer the time before the standard comes into force, the more ambitious the LLCC can be) as with Top Runner the time variable can be used to match the point of LLCC with the benchmark (= Top Runner) values. This would provide the revision of Ecodesign regulations with a clear target from the start of the process.

The Top Runner scheme could benefit from switching to a real MEPS scheme instead of a fleet average. The fleet average requires that manufacturers (or importers) send both the energy efficiency data and sales data for the target year to the authorities. Such a scheme is difficult to check and enforce because measuring an individual product does not conclude about the total suite of products from a manufacturer complying with the requirements. A MEPS approach would open the scheme for products where the market situation is less clear. This might however also require changes in the way stakeholders are consulted in the Top Runner programme.

Regarding the European interest in a Top Runner approach the following can be said based on the analysis in this article. It seems that the appeal of the Top Runner approach is to a large degree conceptual and to a certain extent even more based on an ideal picture than on facts. An example of the latter is the confusion that the dynamic nature of Top Runner implies a short updating cycle, whereas in fact the time between two subsequent requirements is longer for Top Runner than foreseen for Ecodesign. On the question whether the update can be faster the Top Runner approach as such does not provide an answer. The conceptual appeal mainly relates to the principle that the Top

Runner product sets the next requirements. As we have indicated above it is possible to make more explicit this principle in the Ecodesign revision process.

Finally, placing Top Runner and Ecodesign in a broader energy policy perspective it is noted that a product approach, by definition targets energy consumption of individual products. However, total household and commercial electricity consumption is not (completely) controlled with such an approach. First, not all products that are used in households are included in e.g. the Top Runner approach. Second, even if all products were included, the approach does not control the number of products in use, nor their size, nor the duration of their use. So, neither Top Runner nor Ecodesign, nor any other product oriented approach can be the single 'silver bullet' regarding energy saving and CO_2 emission reduction (Siderius 2004).

3.6. **Conclusions and recommendations**

Top Runner is a Japanese programme which addresses energy use in the transport, commercial and private sectors. It is effective in the sense that in general the standards that were set, have been met. The appeal of the approach is embedded in the following characteristics: the simple assessment of the standards (Top Runners) based upon data from products available on the market and its dynamic nature. Moreover the name of the programme has a positive connotation: the most efficient product on the market is the Top Runner.

The EU Ecodesign Directive provides a framework for setting minimum requirements on significant environmental aspects for products placed on the EU market. For 12 product groups from the household, commercial and industrial sectors requirements on energy efficiency (MEPS) and other aspects have been set and it is expected that in the next years MEPS for another 15-20 products will follow. The requirements have a tiered approach and will be reviewed (on average) after almost 5 years.

Both Ecodesign and Top Runner contribute significantly to the energy efficiency targets set by the European Commission and the Japanese government respectively. Comparing the Top Runner approach with the approach offered by the Ecodesign Directive reveals that most of the characteristics of the Top Runner approach can also be found in the Ecodesign Directive although that the “top runner” aspect is somewhat hidden. However, the Ecodesign scheme could exploit the top runner aspect more explicitly by making the benchmark values in the implementing measures starting point for revisions. The Top Runner scheme could benefit from switching to a real MEPS instead of a fleet average. Both schemes would benefit from cooperation through harmonization of measurement methods and criteria. Further harmonization of the test methods will allow better comparison to find the international top runner to set MEPS. A common limitation is the difficulty in dealing with variations in product functionality and with new or improved features. Finally the largest challenge for both schemes is the manageability. Improved planning can provide some relief here, but the main choice is between spending more resources or restricting the scheme to the most important products.

Annex: Top Runner - details on expected and realized efficiency improvements

Product	**First cycle**							**Second cycle**							**Third cycle**						
Subcategory	***ref yr***	***tgt yr***	***improvement***			***improvement [%]***		***ref yr***	***tgt yr***	***improvement***			***improvement [%]***		***ref yr***	***tgt yr***	***improvement***			***improvement [%]***	
			E ref yr	E tgt yr	Unit	expect	real			E ref yr	E tgt yr	Unit	expect	real			E ref yr	E tgt yr	Unit	expect	real
Airconditioners																					
residential, cooling cap. <= 4kW, wall hung non-ducted	1997	2004	3.01	5.05	COP	63	67.8	2005	2010	4.9	6.0	APF	22.4								
residential, cooling cap. >4kW, wall hung non-ducted								2006	2010				15.6								
residential, other								2006	2012				15.6								
commercial								2006	2015				18.2								
Refrigerators	1998	2004	647.3	290.3	kWh/yr	30.5	55.2	2005	2010	572	452	kWh/yr	21								
Freezers	1998	2004	524.8	369.7	kWh/yr	22.9	29.6	2005	2010	482	421	kWh/yr	12.7								
Rice cookers	2003	2008	119.2	106	kWh/yr	11.1	?														
Microwave oven	2004	2008	77.2	70.6	kWh/yr	8.5	?														
Lighting																					
fluorescent	1997	2005	63.1	*74.6*	lm/W	16.6	35.7	2006	2012	84.7	91.2	lm/W	7.7								
bulb-shaped fluorescent								2006	2012				3.2								
Toilet seats	2000	2006	281	253	kWh/yr	10	14.6	2006	2012	186	168	kWh/yr	9.7								
TV Sets																					
CRT	1997	2003	140	104	kWh/yr	16.4	25.7														
LCD, Plasma	2004	2008	142.3	120.5	kWh/yr	?	15.3	2008	2012	?	?	kWh/yr	37								
VCRs	1997	2003	4.55	1.2	W (stb)	58.7	73.6														
DVD recorders																					
non-DTB capable	2004	2008	66	51.2	kWh/yr	?	22.4														
DTB capable	2006	2010	85.9	68.3	kWh/yr	?	20.5														
Computers																					
servers	1997	2005	0.17	0.007	W/MTOPS	?	2500	2001	2007	0.012	0.004	W/MTOPS	69.2	80.8	2007	2011	15.9	6.1	W/GTOPS	62	
personal computers															2007	2011	1.37	0.21	W/GTOPS	84	
Magnetic Disc Units																					
individual disks	1997	2005	1.4	0.14	W/GB	?	1000	2001	2007	0.14	0.04	W/GB	71.4	85.7	2007	2011	0.019	0.005	W/GB	76	
sub-systems															2007	2011	0.094	0.044	W/GB	53	
Copying Machines	1997	2006	155	107	Wh/h	30.8	72.5														
Space Heaters																					

Product	**First cycle**							**Second cycle**							**Third cycle**						
Subcategory	***ref yr***	***tgt yr***	***improvement***			***improvement [%]***		***ref yr***	***tgt yr***	***improvement***			***improvement [%]***		***ref yr***	***tgt yr***	***improvement***			***improvement [%]***	
			E ref yr	E tgt yr	Unit	expect	real			E ref yr	E tgt yr	Unit	expect	real			E ref yr	E tgt yr	Unit	expect	real
Gas space heaters	2000	2006				?	1.4														
Oil space heaters	2000	2006				?	3.8														
Gas Cooking Appliances																					
Burner Section	2000	2006				?	13.9														
Grill Section	2002	2008	317	230	Wh	27.4	?														
Oven Section	2002	2008	1049	836	Wh	20.3	?														
Gas Water Heaters																					
instantaneous and storage	2000	2006				?	4.1														
for space heating only	2002	2008	80.7	83.4	%	3.3	?														
combi	2002	2008	82.1	83.0	%	1.1	?														
Oil Water Heaters	2000	2006				?	3.5														
Vending Machines	2000	2005	2617	1642	kWh/yr	33.9	37.3	2005	2012	1711	1131	kWh/yr	33.9								
Transformers								2009	2014	596	522	W	12.5								
Oil-filled	1999	2006	818	711	W	30.3	13.1														
Molded	1999	2007																			
Routers	2006	2010	6.09	5.1	W	16.3															
Switching Units	2006	2011	6.36	3.96	W/Gb/s	37.7															

Legend:
ref yr: reference year
tgt yr: target year
expect: expected (improvements)
real: realized (improvements)
?: unknown

4.

The role of experience curves for setting MEPS[58]

Abstract

Minimum efficiency performance standards (MEPS) are an important policy instrument to raise the efficiency of products. In most schemes the concept of life cycle costs (LCC) is used to guide setting the MEPS levels. Although a large body of literature shows that product cost is decreasing with increasing cumulative production, the experience curve, this is currently not used for setting MEPS. This article shows how to integrate the concept of the experience curve into LCC calculations for setting MEPS in the European Union and applies this to household laundry driers, refrigerator-freezers and televisions. The results indicate that for driers and refrigerator-freezers at least twice the energy savings compared to the current approach can be achieved. These products also show that energy label classes can successfully be used for setting MEPS. For televisions an experience curve is provided, showing a learning rate of 29 %. However, television prices do not show a relation with energy efficiency but are to a large extent determined by the time the product is placed on the market. This suggests to policy makers that for televisions and other products with a short (re)design and market cycle timing is more important than the MEPS levels itself.

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[58] Published as: Hans-Paul Siderius. 2013. The role of experience curves for setting MEPS for appliances. Energy Policy 59: 762-772.

4.1. **Introduction**

Minimum efficiency performance standards (MEPS) are an important policy instrument to raise the efficiency of products (Geller et al. 2006). Currently MEPS are used in 37 countries around the world for 17 product groups (www.clasponline.org) amongst others Australia, China, Japan[59] and US. In the European Union the Ecodesign Directive[60] provides the framework for setting MEPS. A crucial step in the process is setting the standard, the efficiency level that a product must meet at a certain future year. In most schemes the concept of life cycle costs (LCC) is used to guide setting the MEPS levels. The rationale is that users should not be worse off with the standards, i.e. an increase in product price should at least be compensated by the decrease of other costs, especially lower energy costs. It is assumed that both effects, the higher product price and the lower energy costs, result from setting the MEPS. The LCC calculations require (estimates of) prices of products with higher efficiency, the energy savings for these products and energy prices to calculate monetary savings. As demonstrated by Dale et al. (2009) for MEPS set by the Department of Energy (DOE) in the US the assumption of constant product prices over time overestimated actual retail prices. As a consequence MEPS were set less stringent than they would have been if decreasing product prices would have been used in the calculations.

The concept of experience curves indicates that product cost is decreasing in time with increasing cumulative production (Weiss 2010a). This article uses experience curves to introduce dynamic product prices in LCC calculations, more specifically it investigates how experience curves can be integrated into LCC calculations and the additional energy savings this would deliver. This approach will be illustrated with three products subject to EU Ecodesign MEPS: laundry driers, refrigerator-freezers and televisions. The article is organized as follows. First we introduce the life cycle cost approach as used in EU product efficiency policy and the concept of the experience curves, and we pay attention to some methodological issues of applying experience curves. Then we show two variants how the experience curve can be integrated in the life cycle cost approach and apply this to

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[59] Strictly speaking the Top Runner programme is not a MEPS programme because the target levels refer to the fleet average of the products from a manufacturer or importer. However in practice almost all products meet the targets (Siderius and Nakagami 2012).

[60] OJ L 285, 31.10.2009, p. 10-35.

laundry driers, refrigerator-freezers and televisions. Finally we discuss the results and present conclusions.

4.2. Life cycle costs and experience curves

4.2.1. Life cycle costs

The life cycle costs (LCC) of a product can be expressed by the following formula (Fuller and Petersen 1996, p. 5-3):

$$LCC = PP + PWF \times OE + EoL + RM \qquad [4.1]$$

where LCC is the life cycle costs at the moment of purchase; PP is the product price, including installation costs, paid by the customer; OE are the annual operating expenses; PWF is the present worth factor to discount annual operating expenses during the life time to the moment of purchase; EoL are the costs, disposal costs or recycling charge, or benefits for the end of life (note that these costs might occur at the moment of purchase, e.g. recycling charge); RM are repair and maintenance costs. For simplicity we assume that the end of life, repair and maintenance costs can be neglected or in any case are not related to the energy performance of the product[61]. Also we assume that the annual growth rate of OE, e.g. the electricity price, equals the discount rate (see Kemna (2011, p. 56) for EU data), so that PWF = N where N is the lifetime of the product. Formula [4.1] now simplifies to

$$LCC = PP + N \times OE \qquad [4.2]$$

MEPS (minimum energy performance standards) set requirements on the energy use of products and thereby influence operating expenses. However these requirements can also influence (increase) the product price because more expensive components or a redesign of the product might be needed to comply with the requirements. The concept of LCC enables the balancing of reduced energy costs on one hand and increased product price on the other hand to ensure that the average buyer of the product is not financially worse off when MEPS come into force. Note that this assumes that the buyer of the product is also paying the energy costs of using the product. Using this principle, MEPS

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[61] In EU Member States take-back costs or recycling fees are set per appliance category (refrigerators, washing machines) and do not depend on the energy efficiency.

can be set anywhere between the point that delivers the least life cycle costs (LLCC) and the equal or break-even life cycle costs (ELCC) where the savings of reduced energy costs equal the increase in product price.

In the framework of the EU Ecodesign Directive[62] the procedure for setting MEPS is as follows (see also Annex II of the Directive). Based on technical, market and use analysis one or more base cases are constructed. A base case is a conscious abstraction from reality representing the average product on the market in terms of resource efficiency, emissions and functional performance (Kemna 2011, p. 76). Furthermore the technical and economical analysis result in a number of design options to reduce the energy consumption of the base case, including an estimate of the increase in product price as a result of these design options. Within the Ecodesign framework, the problem to solve is for which design option(s) the LCC are minimal: the LLCC.

4.2.2. Experience curves

In all analyses in the framework of the Ecodesign Directive, the price for a product with certain design options to meet a required energy consumption level is fixed in time. However, there is a large body of literature showing that product cost is decreasing with increasing production due to 'learning' effects (Weiss et al. 2010a). For a broad range of products and technologies it has been shown that:

$$C = C_0 \times CPV^{-b} \qquad [4.3]$$

where C is the cost of the product at cumulative production volume CPV; C_0 is the cost of the first product; b is the experience parameter; $PR = 2^{-b}$ is the progress ratio; $LR = 1\text{-}PR = 1\text{-}2^{-b}$ is the experience ratio, the reduction in costs when cumulative production volume is doubled.

Empirical values of LR for energy relevant products have been found in the range of a few per cent to around 40 %; see overview in Weiss et al. (2010b). **Table 4.1** shows some of the values for products relevant for this article.

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[62] OJ L 285, 31.10.2009, p. 10-35.

Table 4.1 Average learning rates (Weiss et al. 2010b, p. 414, 424)

Product	Average learning rate (standard deviation)
Laundry drier	14 % (± 8%)
Refrigerator	9 % (± 3%)
Freezer	13 % (± 7.5%)
Television	12 % (± 7.5%)
Black and white televisions	13 – 22 %
Color televisions	5 – 7 %
Other consumer electronics	26 % (± 3%)

The experience effect is based upon several parameters regarding the design, the sourcing of materials, components and subassemblies, and the production of the final product (Dale et al. 2009; Weiss et al. 2010b, p. 418). Economies of scale play an important role in the first up scaling of production. In the successive redesign cycles learning is important: designs are made more simple, use less material or less costly material, and need less time to assemble; this holds not only for the final product but also for the components.

The following methodological issues need attention when applying experience curves (Sark et al. 2010). The first is that the theory of the experience curve refers to the decreasing cost of products with increasing cumulative production, whereas in experience curve research often the price of the product is taken as a proxy for the costs of the product. Cost data often are not publicly available because they are considered sensitive information. However the cost structure of a product differs from the price structure of a product (see **Figure 4.1**). The price of a product is determined by product features, marketing and competition. In **Figure 4.1** performance, energy consumption and design are shown as features; these are examples and features may differ per product. The cost of a product is determined by material and component costs, design, manufacturing and overhead. In the long run the price must be at least equal to the costs for the manufacturer to stay in business. According to the model of the Boston Consulting Group (1968) prices reflect costs only in a stable market with sufficient competition.

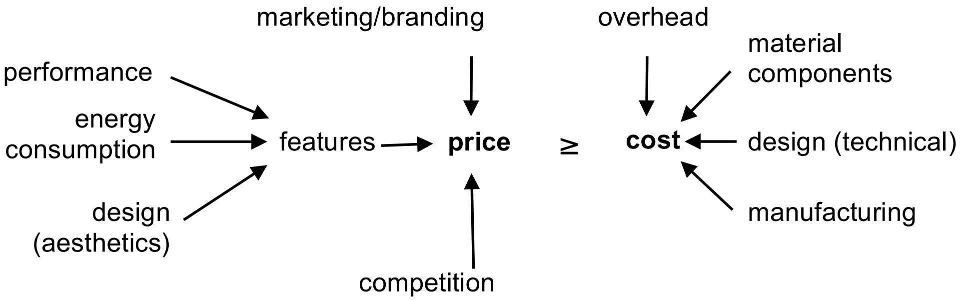


Figure 4.1 Cost and price structure of a product

The difference between (manufacturer) cost and (consumer) price is not only taxation and the mark-up for the retail channel which for simplicity are not shown in **Figure 4.1**, but can also include a price premium the manufacturer can ask for certain outstanding features. A price premium is a price increase that is higher than the cost increase. If energy efficiency is seen as an outstanding feature, more efficient products can not only have higher prices because they cost more, but also because the manufacturer can ask a price premium. So when using prices as a proxy for costs in LCC calculations these ideally have to be corrected for the price premium, which requires information on the extra costs to achieve the higher efficiency level. However, as indicated above cost data often is not readily available and cost data on high efficiency components is probably even more sensitive than ordinary cost data. Therefore, it is proposed not to correct for the price premium of high efficiency products and regard the price as an upper limit estimate of the costs. Another reason to use prices in LCC calculations is that this is the cost that is relevant for the end-user.

A second methodological issue is whether to use one experience parameter for the product or to use an experience parameter for each of the main parts. Disaggregating the product and using multiple experience parameters increases complexity of the data requirements and assumes the same design for all models. The third issue is whether the experience parameter is constant over time or decreases with increasing production volume. According to Sark et al. (2010, p. 22-24) this issue is still open. However, for the application of experience curves for setting MEPS this issue is less relevant because the time horizon is limited to 5, maximum 10 years. In the next section we explore how the concept of the experience curve can be integrated into LCC calculations for setting MEPS.

4.3. Using experience curves for setting MEPS

4.3.1. Introduction

Basically setting MEPS includes finding a point in the energy consumption – time space (see **Figure 4.2**). From the origin (T_0, E_0), the base case or current situation, one or more points are set that reflect the ambitions of the policy. High ambitions mean setting high energy performance values in a short period (T_1, E_2), low ambitions mean setting less high energy performance values after a longer period (T_2, E_1).

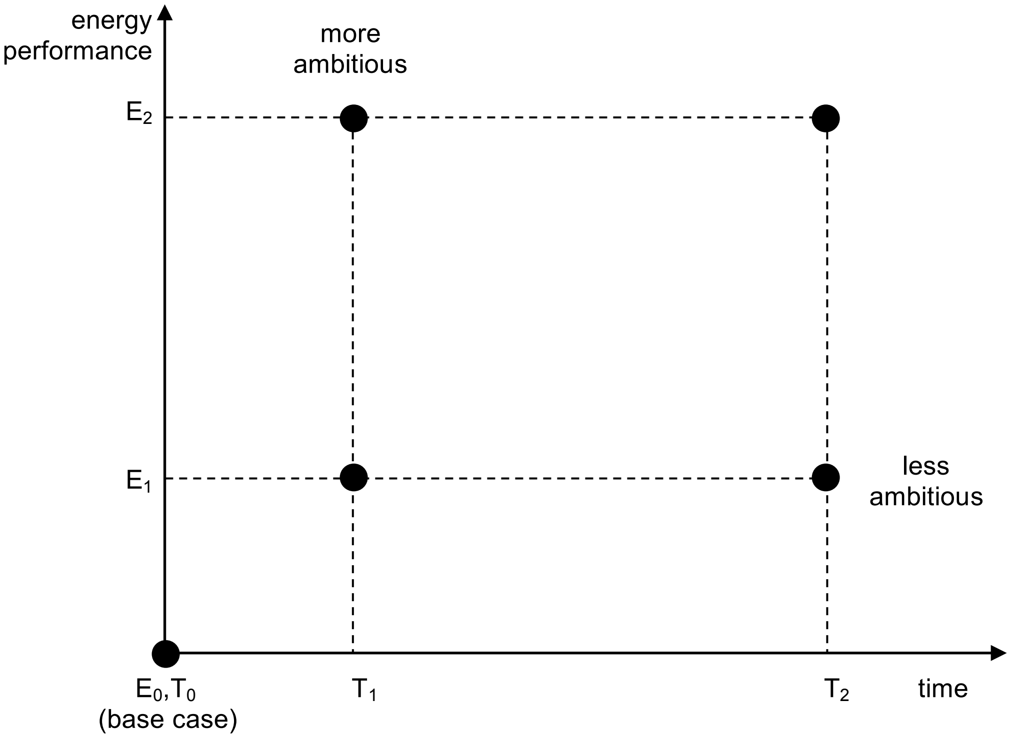


Figure 4.2 Possible positions of a two tiered MEPS

In general Ecodesign requirements (MEPS) come in two tiers, where the first tier at $t=T_1$ has moderate requirements (E_1) and the second tier at $t=T_2$ has more ambitious requirements (E_2); see **Table 4.2** below. For products that also have an EU energy label, the MEPS level is often set at a certain energy class border, e.g. A or A+. Energy consumption values are not spread across an energy class but concentrate at the class border (Waide 2000, p. 833). Improving the efficiency of the product above the class limit but not so much as to achieve the next class, will add costs but does not bring marketing benefits for the manufacturer because the energy class stays the same.

In this article we will use energy classes of the EU energy label (A+++ down to G) as design options to construct the LCC curve. This has several advantages. Prices and sales (production volume) for products can be obtained from market data. Moreover, unlike technical design options that consist of (a combination of) specific technical measures, the energy efficiency level expressed by an energy class can be achieved by various technical options. Also for the energy label classes concrete products often are available on the market (with the exception of the highest energy class A+++), whereas design options are a more theoretical construct. The main disadvantage is that energy classes are only available for a limited number of (consumer) products.

This section explores two ways of integrating the concept of the experience curve into LCC calculations for setting MEPS. The Ecodesign approach uses a fixed time period and calculates the new requirements (MEPS+) that can be achieved in that period, whereas for the Top Runner approach the MEPS+ level is given by the Top Runner product and the time is calculated when this level should come into force.

4.3.2. Ecodesign approach: estimate cost reduction for design options

In the Ecodesign approach the time $t=T_2$ at which the new requirements (MEPS+) will come into force is determined on beforehand. The price reduction at that time is calculated for each design option using the experience curve, a revised LCC curve is drawn and the new LLCC point is determined.

According to Ferioli et al. (2009, p. 2528) a product can be considered as an aggregate of several components, each of which is subject to a (different) learning curve. In this article we consider the product to be a construct of two parts: the base case and the innovative part that realizes the energy savings compared to the base case. In several cases the innovative part can be identified in the product, e.g. a variable speed compressor in a refrigerator or LED-backlighting in a television. For matured products, e.g. washing machines or laundry driers, it can be expected that the experience effect for the base case at $t=T_2$ is very limited because of the large cumulative production volume at $t=T_0$ and the relative short time between T_0 and T_2 compared to the period of several decades over which the cumulative volume has been build up. The innovative part however is relatively new, has only a limited cumulative production volume and will therefore have larger experience effects between T_0 and T_2. Therefore, the price of a product (PP) can be seen as the price of the base case product (PP_{bc}) plus an additional price component for the innovative part (PP_+) where only PP_+ is subject to the experience curve:

$$[PP_+]_{T2} = \alpha^{-b} \times [PP_+]_{T0} \qquad [4.4]$$

with $\alpha = [CPV]_{T2}/[CPV]_{T0}$; b is the experience parameter and CPV is the cumulative production volume of the product

Now, taking energy label classes as design options, PP_+ can be calculated by taking the price difference between the base case product and a more efficient product indicated by energy class X:

$$PP_+ = PP_X - PP_{bc} \qquad [4.5]$$

The X point in the revised LCC curve at $t=T_2$ can now be calculated with the following product price for the product with energy label class X:

$$[PP_X]_{T2} = PP_{bc} + \alpha^{-b} \times [PP_+]_{T0} \qquad [4.6]$$

with $\alpha = [CPV_X]_{T2}/[CPV_X]_{T0}$.

Note that this requires an estimate of the cumulative production volume of the more efficient products (CPV_X). For some of the higher energy label classes, e.g. A+++, this data might not be available at T_0. However, it is assumed that the α for these classes is at least the value of the α for the A+ class.

The calculation above is done for each of the energy label classes above the class of the base case product. The MEPS+ at $t=T_2$ is set at the LLCC of the revised LCC curve.

4.3.3. Top Runner approach: calculate cost reduction needed for achieving more stringent MEPS level

In this case the MEPS+ level is given by the most efficient product on the market at $t=T_0$, the Top Runner product, and the time needed to achieve a price reduction that makes the LCC of this product equal to the base case product is calculated. This is done in two steps:

Step 1: calculate the cumulative production volume that is needed to achieve the required price reduction.

Step 2: calculate the time to achieve that production volume.

Step 1

The MEPS+ level is the efficiency of the Top Runner product at $t=T_0$. The difference in LCC is then:

$$\Delta LCC = [LCC_{MEPS+}]_{T0} – [LLCC]_{T0} \quad [4.7]$$

This difference must be bridged by a reduced product price.

$$\Delta LCC = [PP_{MEPS+}]_{T0} - [PP_{MEPS+}]_{T2} \quad [4.8]$$

As indicated in section 4.3.2 the price of the MEPS+ product can be decomposed in a part for the base case (PP_{bc}) and a part for achieving the MEPS+ requirements (PP_+), so $PP_{MEPS+} = PP_{bc} + PP_+$. The required reduction in product price to satisfy [4.8] is realized by the reduction of PP_+: $\Delta LCC = r \times [PP_+]_{T0}$; thus $[PP_+]_{T2} = (1-r) \times [PP_+]_{T0}$. According to the experience curve $[PP_+]_{T2} = \alpha^{-b} \times [PP_+]_{T0}$. With $\alpha = [CPV_+]_{T2}/[CPV_+]_{T0}$ and $R = 1-r$, $R = \alpha^{-b}$ or $\alpha = R^{-1/b}$. So the cumulative production volume of products that comply with MEPS+ (CPV_+) to achieve the required price reduction is:

$$[CPV_+]_{T2} = R^{-1/b} \times [CPV_+]_{T0} \quad [4.9]$$

Step 2

From [4.9] we know $[CPV+]_{T2}$, the cumulative production volume of products that comply with MEPS+ that is needed to close the gap of ΔLCC by the reduction in product price. The second step is to estimate the time needed to achieve this CPV+ which will then determine T_2, the year to set the MEPS+ standard. This estimate depends on the historical yearly production volumes, but also on the effect of energy labels and (planned) MEPS+ in other countries that could increase the production volume.

4.4. Application to products subject to EU Ecodesign and Energy Label

4.4.1. Introduction

In this section we apply the use of experience curves for setting MEPS to three products that have been subject to ecodesign and energy labeling measures in Europe (and elsewhere): laundry driers, cold appliances (refrigerator-freezers) and televisions. Furthermore these products consume a significant part of EU residential electricity consumption: driers 3 %, cold appliances 14.5 % and televisions 7 % (Bertoldi et al. 2012). Driers are an example of a product where a clear efficient alternative exists: an average drier has energy class B or C, whereas a heat pump drier has class A or better. Also the product price differs significantly, which is the reason why in the EU MEPS for driers are not set at the level of heat pump driers. However, in Switzerland the MEPS for driers is set at the A class as of 1 January 2012. Cold appliances have been subject to energy labels and MEPS for a long time. Several design options exist to make cold appliances more efficient (Presutto and Mebane 2007). In Europe energy labels have driven efficiency improvements for cold appliances. Refrigerator-freezers are the product subcategory with the largest market share in the EU (60 % in 2010). Televisions are products that have a short history of MEPS and energy labels. For these products energy efficiency is less a product feature than for cold appliances; price and performance (screen area, resolution) play a larger role in consumers’ buying decision (Stobbe 2007, p. T3-5). Furthermore screen technology develops fast and new products are placed on the market at a high pace. **Table 4.2** provides references to the ecodesign (MEPS) and energy label regulations and gives the main requirements of the MEPS.

Table 4.2 EU ecodesign and energy label regulations[a] for driers, cold appliances and televisions

Product	Ecodesign (MEPS)	Energy label
Laundry drier	Regulation 932/2012/EU After 1 November 2013: Energy class ≥ C After 1 November 2015: Energy class ≥ B (only for condensing driers)	Regulation 392/2012/EU defines energy classes A+++ down to D
Refrigerator-freezer	Regulation 643/2009/EC After 1 July 2010: energy class ≥ A After 1 July 2012: energy class ≥ A+	Regulation 1060/2010/EU defines energy classes A+++ down to G
Television	Regulation 642/2009/EC After 20 August 2010: energy class ≥ F After 1 April 2012: energy class ≥ D	Regulation 1062/2010/EU defines energy classes A+++ down to G

[a] The text of the Regulations is available at http://eur-lex.europa.eu/en/index.htm.

Besides product specific data also the electricity price is needed for the calculations. We use the average EU consumer price for electricity as used in the ecodesign preparatory studies: 0.18 €/kWh (Kemna 2011, p. 42). The yearly energy consumption is calculated according to the formulas in the energy labeling regulations which are considered to be EU averages. Product prices are related to 2010 price levels by using harmonized indices of consumer prices (HICP) for the EU (Eurostat 2012).

4.4.2. Laundry driers

A household laundry drier mostly consist of a rotating drum driven by an electrical motor, a heating element, a ventilator to move the hot air through the drum with the laundry and controls. Although driers without a drum exist, e.g. cupboard driers which are in essence closets with a heating element and a ventilator, they will not be considered here because in the EU their market share is marginal. Laundry driers can be differentiated according to the way the heat is generated: with gas, with electricity (resistor heater) and by using ambient heat (electrical heat pump). We will not include gas heated driers in this analysis because their application is subject to the availability of a gas infrastructure. Also their market share in the EU is very small: far less than 1%. Furthermore, there is a differentiation between vented and condensing driers, where the vented driers need a vent pipe to outside the dwelling which make them less flexible regarding the location where they can operate. On the EU market the percentage of vented driers shows a steady decline down to less than 30 % in 2008 (4E M&B Annex 2011c, p. 21). According to the analysis in 4E M&B Annex (2011c, p. 29) the difference in energy consumption between vented and conventional condensing driers is small. The main difference is in purchase price: vented driers are cheaper because they have a much simpler construction. The main functional characteristic of a drier is the capacity, the weight related to dry laundry that can be dried in one cycle. The trend is towards driers with larger capacity (> 6 kg).

Energy Efficiency Index and energy consumption values

The EU energy label classes for driers are based upon an energy efficiency index (EEI), which is the weighted annual energy consumption for the standard cotton program at full and partial load (measured) compared to its standard annual energy consumption in kWh. For condensing driers this is $140 \times c^{0.8}$ with c the rated capacity in kg of the drier for the standard cotton program; see Annex VII of the drier energy labeling regulation for more details. Using the formulas in Annex VII of the regulation **Table 4.3** provides an indication of the energy consumption per cycle at full load (7 kg) for products in the various energy label classes.

Table 4.3 EU energy label classes and energy consumption for driers

Energy label class	EEI	Energy consumption at full load		Remarks
		kWh/cycle	kWh/kg	Capacity = 7 kg
B	<76	4.01	0.57	Base case
A	<65	3.43	0.49	
A+	<42	2.22	0.32	
A++	<32	1.69	0.24	So far only achieved by driers with a capacity of 7 kg or more.
A+++	<24	1.27	0.18	Not yet achieved by products on the market.

To calculate weighted consumption for the EEI it is assumed that the energy consumption at partial (= half) load is 0.627 times the energy consumption at full load (M&B Annex 2011c, p. 55). Power consumption in off mode and left on mode is ignored.

Whereas energy label class B can be achieved by conventional condensing driers, class A and more efficient can be only achieved by heat pump driers.

Sales and price data, product life time

Although the first heat pump driers arrived at the EU market end of the 90s, sales only achieved significant numbers in the last years. For sales data per energy label class the market distribution of energy label classes in the Netherlands was used as proxy. Data from Attali et al. (2009, p. 18) shows that for 2008 this distribution, notably the relative sales of A and B classes, is at the EU-8 (DE, DK, FR, IT, NL, PL, PT, UK) average. Price data according to energy classes was obtained from data in consumer magazines in Germany (Test from Stiftung Warentest) and the Netherlands (Consumentengids from Consumentenbond). Attali et al. (2009, p. 43) show that for 2008 the average prices for condensing driers in Germany and the Netherlands are close to the average of the price of condensing driers in EU-8. **Table 4.4** presents sales data for driers and price data for condensing driers in various energy label classes.

Table 4.4 Sales data for driers and price data for condensing driers per energy label class

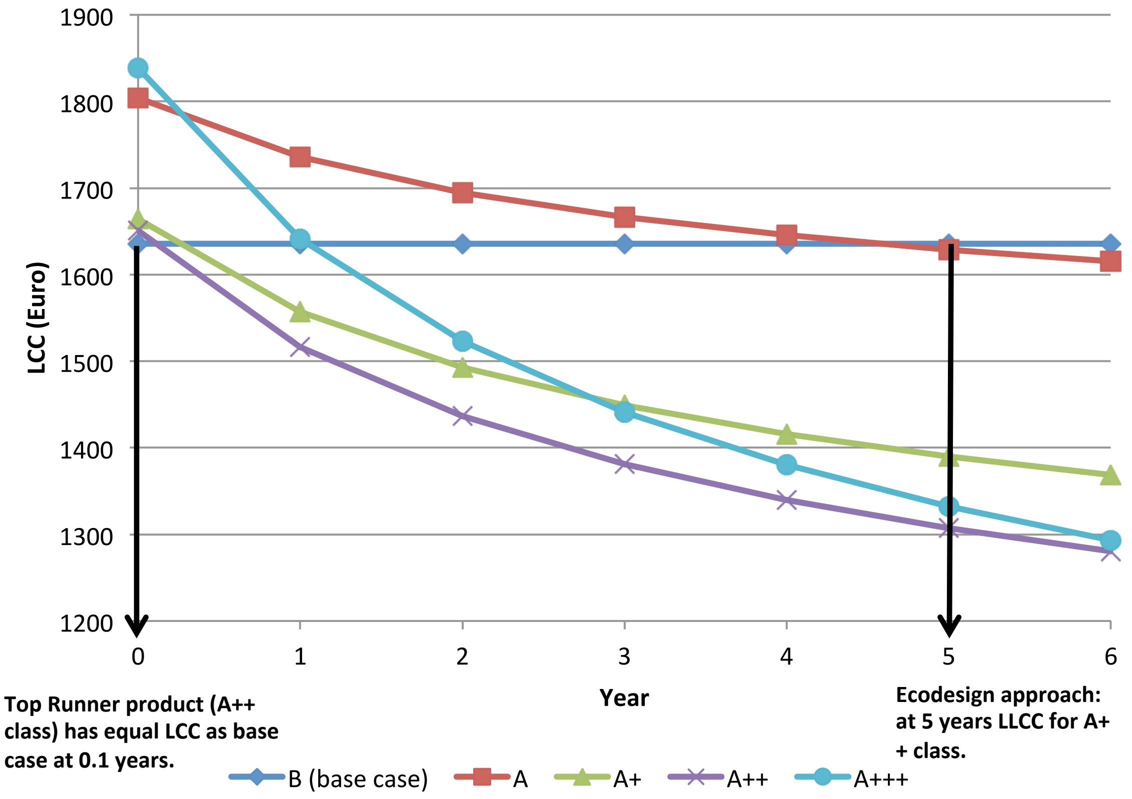
	2005		2006		2007		2008		2009		2010		2011	
Sales	3 707 000		3 957 000		3 817 000		3 862 000		3 299 000		3 322 000		3 253 000	
Market share cond. drier	55 %		57 %		60 %		62 %		64 %		66 %		69 %	
Energy class	€$_{2010}$	%	€$_{2010}$ [a]	%	€$_{2010}$	%	€$_{2010}$ [b]	%	€$_{2010}$ [c]	%	€$_{2010}$ [d]	%	€$_{2010}$ [e]	%
A+++														
A++													727	1
A+									1041[f]				594	10
A	nda		927	1	nda	1	889	3	971	9	861	11	nda	4
B			588	5		15	566	25	592	29	475	38	472	48
C			425	92		82	361	68	nda	62	nda	51	nda	38
D-G			nda	2		10		0		0		0		0

Price data for condensing driers from [a] Stiftung Warentest (2006), [b] Attali et al. (2009, p. 43), [c] Stiftung Warentest (2009), [d] Consumentenbond (2012), [e] Stiftung Warentest (2012); related to 2010 consumer price level with Eurostat HICP; [f]: 1 drier; nda: no data available.

The preparatory study (Lefèvre 2009, p. 356) assumed a € 330 price increase for a condensing drier with heat pump. According to table 4 the average price difference between a drier with energy class B and energy class A in 2008 was € 313 and in 2011 the difference between class B and the average of class A+ and A++ was € 188. This shows that the price increase was more or less reflecting the difference at the time of the study but not the difference at the time the measures should come into force. According to the ecodesign preparatory study (Lefèvre 2009, p. 160), the average life time of a drier is 13 years with a standard deviation of 1.78 years.

Life cycle cost calculation with experience curve

The preparatory study (Lefèvre 2009, p. 365-366) concluded that for condensing driers the base case (between energy class C and B) had the lowest life cycle costs; the option with the largest energy savings (heat pump drier) resulted in 10 % higher life cycle costs. Weiss et al. (2010a, p. 779) found learning rates between 6 % and 28 % for laundry driers; however the lower values are probably underestimated. Weiss et al. (2010b) found learning rates of 30 and 35 % for residential heat pumps. The (cumulative) production volume for heat pump driers is based on the drier sales and the market share of driers with energy label class A or higher; the same value for α (= $[CPV_+]_{T2}/[CPV_+]_{T0}$) is used for each energy label class. Furthermore, it is assumed that the production grows with 10 % per year. Using the 2008 (T_0) data from completed with price estimates for the A+, A++ and A+++ classes at € 1042, € 1200 and € 1500 respectively (Werle et al. 2011), and applying a learning rate of 30 % to the innovative part PP_+, we calculate for the Ecodesign approach that the LLCC point for T_2=5 years moves to energy class A++ with a product price of € 856. According to TopTen data (Werle et al. 2011) the most efficient drier in 2008 had almost the efficiency of the A++ energy class. Since the difference in the life cycle costs between the A++ class and the base case is only € 15, the Top Runner approach would allow for setting the MEPS+ at A++ almost immediately; see **Figure 4.3** where the LCC for the energy label classes A and higher is plotted as a function of the year in which the MEPS+ could come into force.



Top Runner product (A++ class) has equal LCC as base case at 0.1 years.

Ecodesign approach: at 5 years LLCC for A+ + class.

Figure 4.3 LCC for driers with various energy label classes using experience curve

The energy costs for driers are a significant part of the life cycle costs and these costs are directly related to the number of cycles per year the drier is assumed to run. For households using the drier less often than the 160 times per year the regulation assumes, the LLCC point might move. Recalculating using 80 cycles per year the LLCC point for the Ecodesign approach at T_2=5 years stays at the A++ class. The Top Runner approach would now allow setting the A++ class at 5.2 years because the difference in LCC between the base case and the A++ class is now larger.

4.4.3. Refrigerator-freezers

Refrigerator-freezers have as main function to provide two or more temperature controlled compartments to preserve food and drinks. Given a certain difference between the ambient temperature and the temperatures in the compartments, the volume of the appliance is the main functional aspect that determines the energy consumption. Compared to other parts of the world the volume of refrigerator-freezers on the EU market is relatively small: the average refrigerator compartment(s) volume in the US, Canada and Korea (around 400 l) is almost twice the average volume in the EU (just over 200 l) and the average freezer compartment(s) volume is more than two times the average volume in the EU (200 l versus 75 l) (4E M&B Annex 2010, p. 10). Moreover the average volume in the EU for both refrigerator and freezer compartments is almost stable over time. Therefore we assume that the average price and energy efficiency of refrigerator-freezers in the EU over time is not influenced by the volume.

Energy Efficiency Index and energy consumption values

The EU energy label classes for cold appliances are based upon an energy efficiency index which is the annual energy consumption calculated from the measured energy consumption per 24 hours multiplied by 365 compared to its standard annual energy consumption. The standard annual energy consumption is calculated with a formula that takes into account the volume and design temperatures of the compartments and various other features such as the climate class and the presence of a frost-free frozen food compartment. Furthermore, 10 refrigeration appliance categories are distinguished, each having a different formula; see Annex VIII of the household refrigerating appliances energy labelling regulation for details. Using the formulas in Annex VIII of the regulation, **Table 4.5** provides an indication of the energy consumption of a refrigerator-freezer with a refrigerator volume of 210 l and a freezer volume of 80 l, resulting in an equivalent volume of 382 l, for various energy label classes.

Table 4.5 EU energy label classes and energy consumption for refrigerator-freezers

Energy label class	**EEI**	**Energy consumption** kWh/day	kWh/l, year	**Remarks** Equivalent volume: 382 l
A	< 55	0.90	0.86	No longer allowed on the market.
A+	< 44[a]	0.72	0.69	
A++	< 33	0.54	0.52	
A+++	< 22	0.36	0.35	Most efficient products on the market.

[a] 42 as of 1 July 2014

Sales and price data, product life time

Data on market shares for cold appliances and average price data for refrigerator-freezers without no-frost was obtained from GfK market services (www.gfk.com). The data covers 10 EU countries (AT, BE, DE, ES, FR, IT, NL, PT, SE, UK) accounting for 86 % of total EU sales. **Table 4.6** presents sales and price data for refrigerator-freezers in various energy label classes.

The actual price data can be compared with the prices used for the LCC calculation in the preparatory study (Presutto and Mebane 2007, p. 67). The base case refrigerator-freezer without no-frost had energy label class A and a price of € 485, the LLCC product had energy label class A+ and a price of € 586. The BAT (best available technology) product had energy label class A++ and a price of € 852. From **Table 4.6** it follows that the price of refrigerator-freezers with energy label class A in 2010 was € 330 and those with energy label class A++ € 557. We note that the prices used in the preparatory study are already higher than the average prices on the market at the time of the study and certainly higher than the prices at the time the measures should come into force. According to the ecodesign preparatory study (Faberi 2007, p. 36), the average life time of cold appliances is 14 years with a standard deviation of 4 years.

Table 4.6 EU sales data for cold appliances and average price data for refrigerator-freezers non no-frost per energy label class

	2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011	
Sales	14 351 600		14 741 800		14 652 300		15 521 200		16 794 600		15 961 700		16 628 900		16 173 000		15 652 200		15 253 700		15 030 400		14 460 000	
Market share FF[a]													59 %		59 %						60 %			
Market share non no-frost FF[a]											62 % [b]		60 % [b]		58 % [b]		57 % [b]		55 % [b]		54 %		52 %	
Energy label class*	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%	$€_{2010}$	%
A+++																							757	1
A++									1004	<1	901	1	836	1	710	2	671	3	633	6	557	8	512	11
A+			483[c]	1	802	2	856	4	747	8	682	11	641	15	583	20	524	26	490	32	432	40	389	48
A	885	20	713	29	663	38	591	45	545	51	495	55	467	60	443	61	390	59	353	55	330	48	302	40
B	658	35	600	36	570	36	527	34	456	28	410	25	390	18	361	12	320	8	367	6	313	4		
C	546	31	500	24	487	16	459	12	438	9	428	6	409	5	462	4	462	2	393	1				
D-G		13		12		7		3		4		2		1										

[a] FF: fridge-freezers; market share (Bertoldi et al. 2012); [b] estimate based on trend in market share non no-frost all cold appliances (Bertoldi et al. 2012, p. 38); [c] average not representative because based on too small sample.

Sources: market share cold appliances: (Eckl 2011); average price data for 10 European countries (AT, BE, DE, ES, FR, IT, NL, PT, SE, UK) refrigerator-freezer no non-frost obtained from GfK market services and related to 2010 consumer price level with Eurostat HICP.

Life cycle cost calculation with application of the experience curve

The learning rates Weiss et al. (2010a) found for refrigerators, including refrigerator-freezers, are fairly consistent around 9 %. Assuming that the refrigerator-freezer without no-frost has the same distribution of energy label classes as cold appliances in general, **Table 4.6** allows the calculation of the learning rates for A+ and A++ products: 12 % for A+ class and 11 % for A++ class. Applying a conservative learning rate of 9 % and using data of **Table 4.6** for 2005 (T_0) completed with a price estimate of € 1200 for the A+++ class, we calculate for the Ecodesign approach that the LLCC point for T_2=5 years is energy label class A++. The most efficient product in 2005 had an A++ energy class. The Top Runner approach would allow for setting the MEPS+ at A++ at T_2=3.2 years (see **Figure 4.4**).

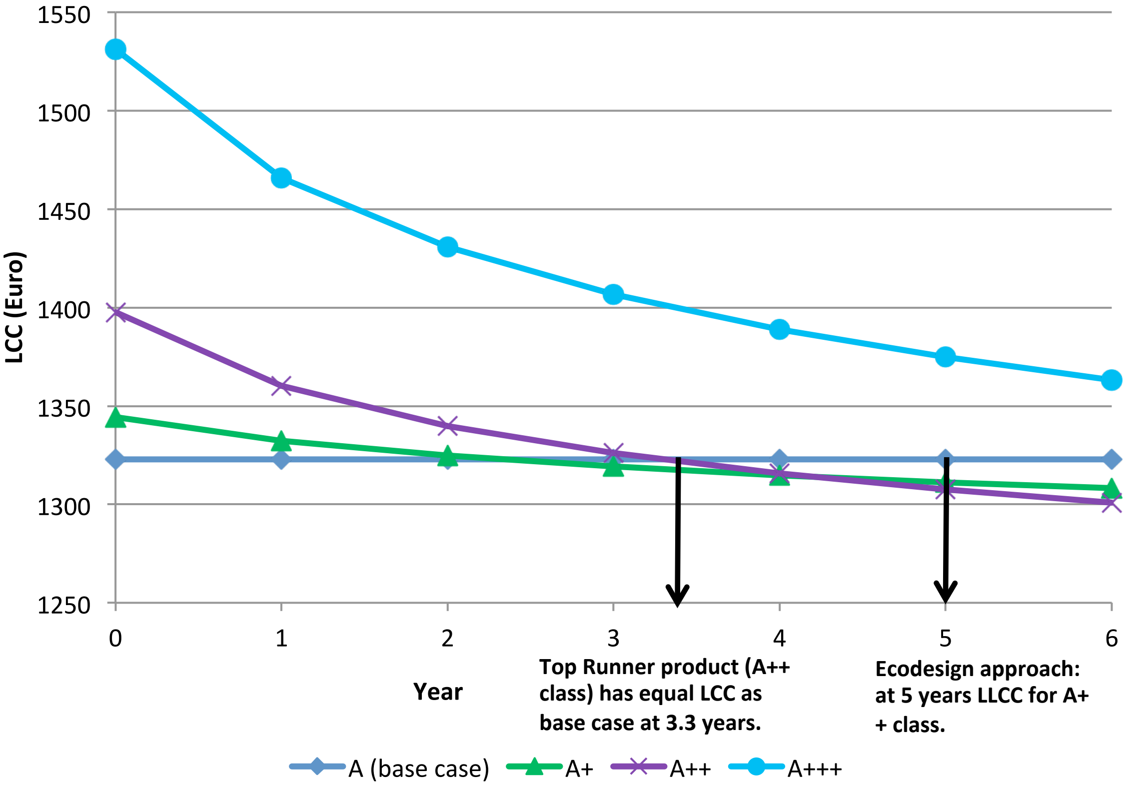


Figure 4.4 LCC curves for refrigerator-freezers with various energy label classes using experience curve

4.4.4. Televisions

A television is an electronic product with the main function to receive, process and display TV transmission signals while reproducing the accompanying sound. The TV signals can arrive from a variety of sources: satellite, cable, terrestrial and internet. The power consumption of a television is determined by various factors of which the screen area is the most important; in essence a television is producing light, radiating from a surface, the screen. Using flat screens with CCFL (Cold Cathode Fluorescent Lamp) or LED (Light Emitting Diode) backlighting enabled a significant increase of the screen size and lower power consumption compared to CRT (Cathode Ray Tube) screen technology. Also Plasma technology is used for television screens but this is a less efficient technology. Moreover, Plasma televisions have a small and declining market share in the EU (European Commission 2012a, p. 29) and will not be considered, nor will beamers and rear projection televisions. Furthermore, the screen area is a major determinant of the cost (and price) of a television and the trend is towards increasing screen areas (Park et al. 2011, p. 8). Therefore in the analysis we concentrate on screen sizes of 40 and 42 inch (102 en 107 cm).

Energy Efficiency Index and energy consumption values

The EU energy label classes for televisions are based upon an energy efficiency index which is the measured power consumption in on-mode[63] compared to a reference power consumption. This reference power consumption is P_{basic} + A×4.3224 where P_{basic} is the power consumption in W for the electronics and A the screen area in dm^2; see Annex II of the television energy labeling regulation for more details. Using the formulas in Annex II of the regulation **Table 4.7** provides an indication of the power consumption and the annual energy consumption based upon 4 hours on per day for a television with a screen size of 42 inch diagonal, with a screen format of 16:9 resulting in a screen area 49 dm^2.

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[63] Standby and off mode power consumption of televisions is regulated through the ecodesign measure for televisions.

Table 4.7 EU energy label classes and energy consumption for televisions

Energy label class	**EEI**	**On mode consumption**		**Remarks**
		Power (W)	Energy (kWh/year)	Screen area: 49 dm^2
D	< 0.80	184	269	
C	< 0.60	138	202	Most efficient Plasma televisions
B	< 0.42	97	141	
A	< 0.30	69	101	
A+	< 0.23	53	77	
A++	< 0.16	37	54	Most efficient TVs on the market
A+++	< 0.10	23	34	

Sales and price data, product life time

The first televisions with energy class A appeared on the EU market early 2010, the first A+ televisions early 2011 and since May 2012 televisions with energy class A++ are available (TopTen 2012, p. 3). **Table 4.8** provides sales and price data for televisions in various energy label classes. Data for the sales percentages is based on estimates from two television manufacturers and the distribution of models tested by the German magazine computer technik. Price data for 40 and 42 inch LCD televisions is based on publications in computer technik and the consumer magazine Test.

Table 4.8 Sales data for televisions and price data for 40 and 42 inch LCD televisions per energy label class

	2006	2007	2008		2009		2010		2011		2012	
Sales (millions)	36. 1	39.7	42.9		49.6		55.3		53.4			
Market share FPD	55 %	79 %	92 %		98 %		100 %		100 %		100 %	
Average EEI			0.90		0.73		0.54		0.41		0.32	
Energy label class			€$_{2010}$	%	€$_{2010}$	%	€$_{2010}$	%	€$_{2010}$	%	€$_{2010}$	%[a]
A+++	nda	nda										
A++												1
A+										6	676	32
A							690	5	625	41	789	41
B			1959	<<1	nda	5	1261	30	796	29	875	18
C			1556	<1	1039	26	852	61	504	18	1758	8
D-G			1902	99	1110	68	1374	4	466	6		

FPD: flat panel display; nda: no data available; price data (street price Germany) for 40 inch and 42 inch televisions from Stiftung Warentest and computer technik, related to 2010 consumer price level with Eurostat HICP; nda: no data available; [a] estimates based on first 6 months.

The preparatory study did not provide cost estimates for specific televisions but made a general remark on decreasing costs and assumed that all options for improving energy efficiency would be cost neutral (Stobbe 2007, p. T7-25). The average useful product life of a television is estimated to be 7 years (Stobbe 2007, p. T2-29). Older televisions are still being used as long as they function but the number of hours in use is considered to be much lower than 4 hours per day.

Life cycle cost calculations with application of the experience curve

The market data in **Table 4.8** shows a large improvement in energy efficiency since 2008: the average EEI decreased from 0.90 in 2008 to 0.32 in 2012. This is partly a result of increasing screen size of televisions: televisions with a larger screen size can more easily achieve a lower EEI. For televisions price data does not seem to correlate with energy label class. On the contrary, in the sample of 40 and 42 inch televisions sold in Germany in 2010 and the sample of the first half of 2012 the most efficient televisions were less expensive than the others, and for 2011 the most efficient televisions (energy label class A) were less expensive than televisions with energy label class B. UK data for televisions sold in 2011 on the relation between energy label class and price shows that the correlation is spurious: the screen size is the variable that affects both. Televisions with larger screen size are more expensive and can more easily achieve a better energy label class. The data suggests that for televisions energy efficiency as such is not a feature that manufacturers can ask a price premium for. Because the energy label for televisions has only been mandatory since the end of 2011, this might change in the future. However, this probably would require a higher consumer priority for energy efficiency when buying a television.

Data from WitsView, a market research firm, published by the LCD TV association (www.lcdtvassociation.org/lcdtvmatters.html) on worldwide street prices for 42 inch LCD televisions show a strong relation between price and the time the product is on the market: the average price dropped exponentially from US$ 6374 in the last quarter of 2004 to US$ 976 in the second quarter of 2009. Prices of televisions differ by screen size; however variation is much less when considering prices per m^2 screen area for different sizes. The learning rates in Weiss et al. (2010b, p. 424) for televisions are 13 and 22 % for black-and-white TVs and 5 and 7 % for color TVs; all relate to CRT technology. For LCD televisions a learning rate can be estimated by using the average worldwide street price per m^2 (sales weighted for various screen sizes) and the worldwide cumulative shipment data from DisplaySearch (www.displaysearch.com); see **Figure 4.5**. With b=0.493 the learning rate is 29 % which is just within the range of 26 % ± 3 % Weiss et al. (2010b, p. 414) indicate for "other consumer electronics".

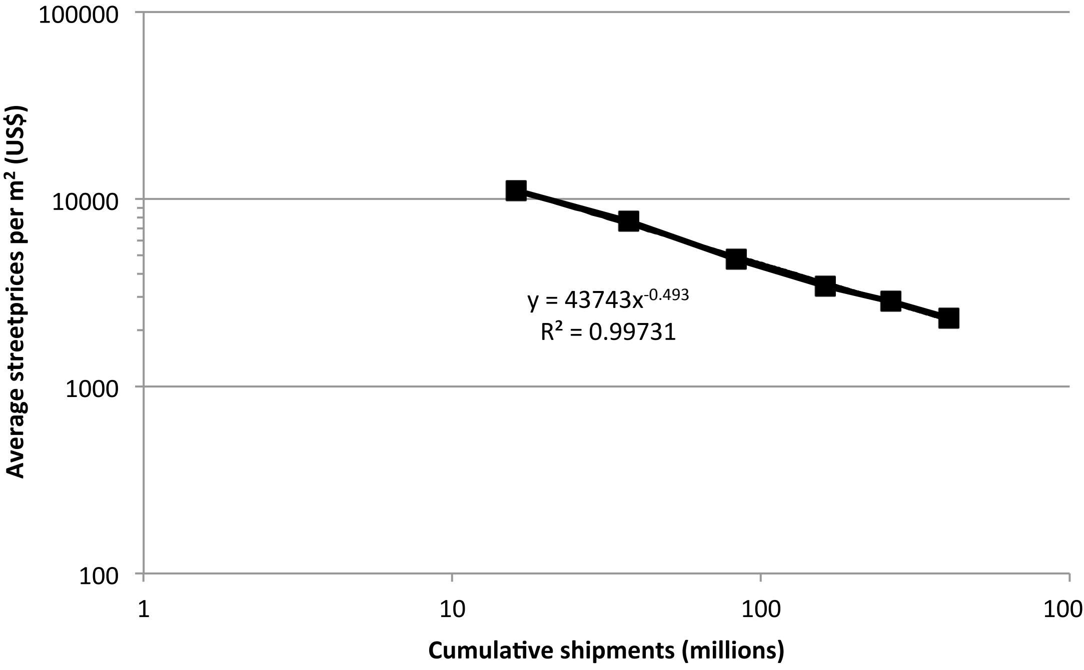

Figure 4.5 Experience curve for LCD televisions

Because there is no relation between price and energy label class, a life cycle cost calculation using prices per energy efficiency class does not make sense. One could argue that further efficiency improvements which are inherent to developments to satisfy other consumer demands, e.g. flatter panels, better contrast, will follow the development of the average EEI as shown in **Table 4.8**: EEI = $1.20\times e^{-0.265(\text{year}-2007)}$. This would mean that in 2016 the average EEI of products offered on the market would be 0.11. The concept of the experience curve could be applied in those cases where specific costs can be allocated to serve only an improvement of efficiency.

4.5. Discussion, conclusions, recommendations

In the foregoing section we applied the concept of experience curves in setting minimum efficiency product standards (MEPS) in a European context, that is for three products subject to EU ecodesign and energy labeling measures. In this section we first summarize and discuss the results. Then we take a broader perspective on what the results could mean for the application of the life cycle concept in setting MEPS and provide recommendations for policy making.

First, the results indicate that for condensing driers and refrigerator-freezers (non no-frost) also in the EU actual average prices are lower than the prices assumed in the preparatory studies for setting the MEPS. This means that there is room for setting more stringent MEPS by taking the experience curve into account. **Table 4.9** shows the results when applying the experience curve for setting MEPS. Additional savings for the EU in 2025 have been calculated assuming first that all products would have been replaced and comply with the levels according to the experience curve approach. The second assumption is that the savings per product are half of difference in consumption between the energy class according to the current approach and the experience curve approach, thus accounting for the fact that also under the current approach products with a better energy label class would be sold. This is a simplistic approach avoiding the use of complex stock models.

Table 4.9 Overview of results

Product	**Current approach**	**Approach with experience curve**		
	LLCC point [energy class]	***Ecodesign approach with T_2 = 5 years [energy class]***	***Top Runner approach [energy class]***	***Additional savings EU in 2025 [TWh/year] (% of savings with current approach)***
Condensing drier	B	A++	A++ with T_2=0.1 year	5 (143 %)
Refrigerator-freezer (no non-frost)	A+	A++	A++ with T_2=3.3 year	6 (100 %)
LCD television (40, 42 inch)	no LLCC point in preparatory study	Not possible to use experience curve approach because no relation between price and energy label classes		

The results further show that the Top Runner approach allows the same requirements to be set earlier. The reason is that in the Top Runner approach the price gap to be bridged is the difference in LCC with the base case product at T_0, whereas in the Ecodesign approach it is the difference in LCC at T_0 and T_2 for the LLCC point. A consequence is that the product price in the Top Runner approach is higher.

For televisions the ecodesign preparatory study did not provide cost estimates for the base cases. Price data for 40 and 42 inch LCD televisions did not seem to relate to the energy label classes. However the price is exponentially related to the time the product is on the market. Furthermore, energy efficiency of television has improved greatly in the last years: the EEI decreased from an average of 0.90 in 2008 to 0.32 in 2012. We will discuss below the implications for using an LCC approach (based on market prices) to set MEPS for televisions.

For a more general discussion on the concept of LCC for setting MEPS two issues are important:

- Correlation between price and energy efficiency class.
- Prices as proxy for costs.

The correlation between prices and energy efficiency is the basic rationale for LCC calculations. For dryers and refrigerators there is in general a correlation between price and energy label class: the higher the energy label class (the more efficient the product) the higher the price. Some exemptions for refrigerators are due to special features of certain products, e.g. ice-through-the-door, a special design, that allow the manufacturer to ask a higher price despite the lower energy efficiency class. There seems to be no correlation for televisions. Televisions as computers, smart phones and set-top boxes are products with a short (re)design and market cycle with the product price decreasing exponentially over time after market introduction until the product is superseded by a new model that has more functionality or a better performance. Distinction can be made between a major redesign which marks a significant step in performance or functionality, or a minor redesign which marks a gradual improvement. These products pose several challenges for LCC calculations. Cost and prices are not related to energy efficiency improvements but to new features or better performance. Since these are essential for the manufacturer to remain competitive, information on future developments will be scarce, certainly regarding major redesigns. Also some features which are announced or present in some models may not be accepted as fast as manufacturers would like; examples for televisions are high definition television in the 90s and currently 3D television. Other improvements, e.g. OLED screens, encounter difficulties when scaling up to mass production for large(r) screens (Kuhlmann and Porteck 2012, p. 23). Improvement on certain features, e.g. the screen thickness, may result in or need improvements in energy efficiency. Only for a few specific parts, notably the power supply, efficiency improvements can be regarded isolated and the additional costs calculated separately. A first solution to address the challenges is not to use life cycle costs for these products but negotiate with manufacturers which energy efficiency improvements can be absorbed in (re)design cycles and how long it would take before all models could profit. The experience curve can play a role by estimating a reasonable time period for setting MEPS. A second solution is to take the current EEI development and extrapolate this to the future for setting the next MEPS levels. This assumes that this level is achievable with the same but improved technologies that are used today and that there are no specific extra costs. Both assumptions can be tested by technical research, see e.g. the improvement in efficacy of LEDs (Park et al. 2011, p. 37). Thirdly, the experience curve can be used for specific situations, e.g. improvements in power supply efficiency, where the cost of improvement of energy efficiency can be isolated and that are not on the trajectory of improved performance or more features.

The second issue is the use of prices as proxy for costs. The data confirm part of the model of the Boston Consulting Group: without sufficient competition prices are poor proxies for costs regarding energy efficiency. For dryers with energy label class A average prices are fairly constant – or even rise – from the introduction on the market until a market share of around 10 % (see **Figure 4.6**) at which prices drop. This suggests that until the price drop the experience effect is not reflected in the price of the product. Refrigerator-freezers are mature products where the experience effect is used from the beginning. Prices drop significantly as the market develops and then decline according to a linear line.

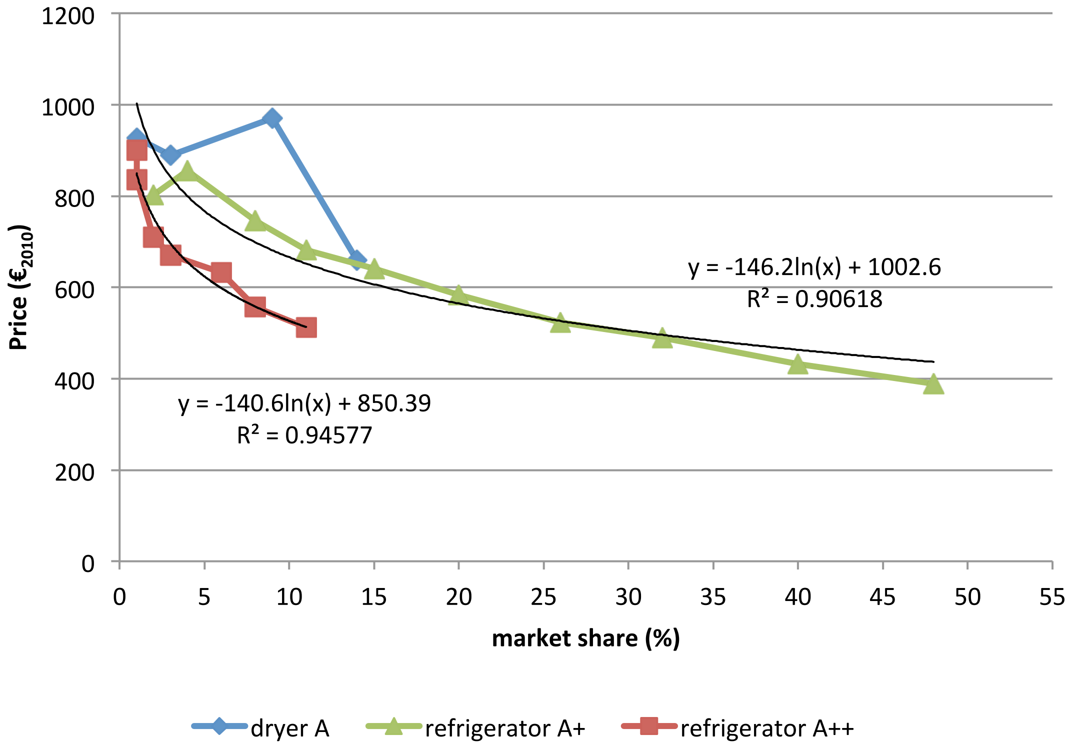

Figure 4.6 Price versus market share for driers and refrigerator-freezers

What does the foregoing imply for energy efficiency policy regarding MEPS and energy labeling? The EU energy label can support the LCC calculations for setting MEPS. The energy label classes stratify the market in efficiency bands for which data on market share and price can be collected. Also the energy label classes are in principle a neutral way to indicate energy efficiency improvements, i.e. they do not refer to a specific technology, although in some cases (driers) it is clear that a certain technology (heat pump) is needed to achieve a better energy class[64]. Furthermore the energy label makes competition on energy efficiency visible which results in lower prices and stimulates developing products in higher energy label classes. In this article this has been demonstrated by driers and refrigerator-freezers. However energy label classes can only support LCC calculations if there is a relation between energy label class and price. Without this relation the use of LCC calculations for setting MEPS is questionable anyway. For products characterized by a

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[64] There are tumble driers on the market that achieve energy class A without a heat pump but with a programme using cold air and a long (> 8 hours) drying time. The long drying time and the resulting increased wear of the fabric however disqualify such programmes for use in practice by consumers.

short (re)design and market cycle, driven primarily by increasing performance and features (and not energy efficiency) additional mechanisms for setting MEPS are needed. Energy efficiency improvements that are related or even needed to realize improved performance can be considered to come for free with the increased performance. The parameter that influences cost in this case is the point in time of placing the product on the market after the first introduction of improved performance or new features. These are first introduced in high-end products, because these products allow for recovery of the costs and then as costs decrease implemented in other price segments. As indicated in section 4.3.1 setting MEPS is defining one or more points in the energy consumption – time space. If lower energy consumption is not related to price as such, but to the time the product is placed on the market, then the setting of MEPS in time is determined by the price decrease of the product. For these products an energy label still can be useful to visualize the energy efficiency of the product and to enhance the importance of energy efficiency for consumers.

5.

Setting MEPS for electronic products[65]

Abstract

When analysing price, performance and efficiency data for 15 consumer electronic and information and communication technology products, we found that in general price did not relate to the efficiency of the product. Prices of electronic products with comparable performance decreased over time. For products where the data allowed fitting the relationship, we found an exponential decrease in price with an average time constant of -0.30 [1/year], meaning that every year the product became 26% cheaper on average.

The results imply that the classical approach of setting minimum efficiency performance standards (MEPS) by means of life cycle cost calculations cannot be applied to electronic products. Therefore, an alternative approach based on the improvement of efficiency over time and the variation in efficiency of products on the market, is presented. The concept of a policy action window can provide guidance for the decision on whether setting MEPS for a certain product is appropriate. If the (formal) procedure for setting MEPS takes longer than the policy action window, this means that setting MEPS will not lead to accelerated efficiency improvements. We found short, i.e. less than three years, policy action windows for graphic cards, network attached storage products, network switches and televisions.

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[65] Published as: Hans-Paul Siderius. 2014. Setting MEPS for electronic products. Energy Policy 70: 1-13.

5.1. Introduction

In the last few decades electronic products like televisions, computers, monitors, laptops, tablets, mobile phones, and set-top boxes have invaded our lives. The impact on household and commercial electricity consumption is significant and is expected to grow (Ellis 2009). Bertoldi et al. (2012, p. 35) estimate that electronic products use 17% of the residential electricity consumption in the European Union (EU). Therefore, electronic products are increasingly the target of energy efficiency policies. Up to now, policies focused mainly on reducing standby power consumption e.g. to implement the IEA 1 Watt standby target (Jollands et al. 2010), whereas the current focus is also on the efficiency of the product when in the on-mode.

Table 5.1 Overview of energy efficiency policies for electronic products

Product	**Efficiency requirements**		**Energy labels**	
	Voluntary	***Mandatory (MEPS)***	***Voluntary***	***Mandatory***
Computer		Ecodesign (EU) Top Runner (Japan)	ENERGY STAR (US, EU) Top Runner (Japan)	
Graphic card		Included in Ecodesign (EU) requirements for computers	Included in ENERGY STAR (US, EU) specifications for computers	
Hard disk		Included in Ecodesign (EU) requirements for computers Top Runner (Japan)	Included in ENERGY STAR (US, EU) specifications for computers Top Runner (Japan)	
Monitor		Proposal revised requirements displays Ecodesign (EU)	ENERGY STAR (US, EU)	Proposal EU energy label
Network attached storage (NAS)				
Notebook		Ecodesign (EU)	ENERGY STAR (US, EU)	
Printer, including Multifunctional devices (MFD)	Voluntary Agreement under Ecodesign (EU)		ENERGY STAR (US, EU)	
Power supply (internal)		Included in Ecodesign (EU) requirements for computers	Included in the ENERGY STAR (US, EU) specifications for computers	
Router, Streaming client, Network switch		Top Runner (Japan)	ENERGY STAR (US, EU)	
Set-top box	Voluntary Agreement under Ecodesign (EU)		ENERGY STAR (US) in preparation	
Television		Ecodesign (EU) Top Runner (Japan)	ENERGY STAR (US) Top Runner (Japan)	Energy label (EU, US)

Table 5.1 provides an overview of current policies for electronic products discussed in this article in the EU, Japan and the United States (US). Most experience in energy efficiency policies for electronic products has been with the introduction of (voluntary) energy labels, mainly ENERGY STAR in the US and EU. It is only recently that mandatory minimum efficiency performance standards (MEPS) have emerged, notably within the framework of EU Ecodesign Directive 2009/125/EC[66], but also in the Top Runner programme in Japan. These first experiences have highlighted some problems that seem typical for electronics, e.g. how to deal with the high speed of market development, the ongoing introduction of new features and functionalities, the merging of products, and the disappearance of products from the market. Moreover, the question arises as to whether the life cycle cost methodology for setting MEPS that is used for household appliances, such as cold appliances, washing machines, dishwashers, and dryers, is also suitable for electronic products.

The classical method of setting MEPS is straightforward and the main steps can be summarised as follows. First, the energy efficiency of one or more representative products on the market is assessed. Second, the technical options to improve the energy efficiency and thereby – ceteris paribus – lower the energy consumption are explored and for these options the life cycle costs (LCC) for consumers are calculated. The LCC include the price of the product, the running costs over the lifetime of the product, e.g. the cost of energy, consumables and maintenance, and the cost at the end-of-life of the product. Third, the MEPS are set at a certain level, e.g. at the lowest or least life cycle cost (LLCC), and come into force at a certain date. This approach is used by the Department of Energy (DOE) in the US for setting appliance standards (US DOE 2006, p. 20) and by the European Commission in the EU to set ecodesign requirements (Kemna et al. 2005). The rationale for this approach is that the MEPS should deliver both energy savings and net cost savings for consumers.

Using LCC for setting MEPS assumes that the cost for improving the energy efficiency of the product is related to the price of the product: the price increases due to the cost for changing the product to improve the efficiency. If this is correct, the LCC covers the impact of the measure on manufacturers and on consumers. However, the relation

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[66] OJ L 285, 31.10.2009, p. 10-35.

between the costs and the price of a product is not straightforward. Although in the long run the price for a product needs to be higher than its costs for the manufacturer to stay in business, the price is determined by factors other than the costs alone. Costs for manufacturers are costs of materials and components, design and production costs, and overhead costs, including research and development, marketing, and sales. The price is determined by the competition on the market, the sales channels used, brand, design (aesthetics), and features that consumers are willing to pay (extra) for. Another difference is that the price of a (consumer) product is made publicly available whereas costs for manufacturers are rarely declared because these are regarded as competition sensitive data and therefore confidential. The costs can be estimated by independent engineering analysis, but this is more difficult for future developments, new features, and functionalities.

In general the assumption that the price of a product is related to the energy efficiency holds true for household appliances and lighting, and also for industrial products like electrical motors, pumps and fans. However, Siderius (2013a, p. 770) found for televisions that price did not correlate with the energy efficiency classes of the EU energy label. In that case LCC cannot guide MEPS and indeed the Ecodesign preparatory study for televisions only made a general remark on decreasing costs and assumed that all options for improving energy efficiency would be cost neutral (Stobbe 2007, p. T7-25).

The aim of this article is first to review for 15 consumer electronic (CE) and information and communication technology (ICT) products the assumption that is the basis for applying life cycle cost analysis, i.e. that energy efficiency is related to the price of the product. The second aim is to provide an alternative in case this assumption is challenged and to provide input to the development of a methodology that can be used for development of efficiency policies for electronic products in general. Literature on appliance prices is mostly concerned with development of prices or efficiencies over time for household appliances (Dale 2009, Desroches et al. 2013). Literature on energy efficiency policy for electronic products is scarce and mostly relates to ENERGY STAR and the energy savings of the ENERGY STAR program (Webber and Brown 2000, Sanchez et al. 2008), or the development of criteria for computers (Lim and Schoenung 2011).

This article is organized as follows. Section 5.2 describes the data of 15 electronic products and the methods used to analyse this data. In section 5.3 we present both the results of the analysis, regarding the relation between efficiency and price, and our alternative for setting MEPS for products where the traditional LCC approach is not suitable. In section 5.4 we discuss the findings, and section 5.5 considers conclusions and policy implications.

5.2. Material and methods

This section describes the data collection, the selection of efficiency parameters, and indicates the methods used to analyse the data.

Data were collected from a single, neutral, i.e. not dependent on manufacturers, source, the biweekly German computer magazine c’t (Computer Technik) (www.heise.de/ct). c’t tests a variety of CE and ICT products, including measurements of power consumption and performance. Using a single source guarantees consistency between the data since the same measurement method is used for all the products. In general, c’t uses test methods based on international standards, where available. Changes in measurement methods and metrics over time are indicated in the publications. Although the tests do not cover all products on the market and some single publications focus on specific types of products, it is assumed that the data reflecting the interest of c’t readers is a fair representation of the market. For most products, several tests per year are published to closely follow new models appearing on the market. For all products, data are available for at least four years, and for most products data are available for ten or more years. **Table 5.2** gives an overview of the type of data collected for each product. Descriptive statistics for price and performance and efficiency variables can be found in the Annex.

Table 5.2 Overview of collected data

Product	Years[a]	N	Type of data			
			Price	*Performance*	*Energy*	*Efficiency*
Computer: Personal Computer (PC), Bare bone (BB), Main board (MB)	2000-2013	997	Street price [€$_{2010}$]	Graphic performance [3DMark], Office processing [SYSMark]	Power consumption on mode [W]	[3DMark/W], [SYSMark/W]
Graphic card	2006-2012	139	Street price [€$_{2010}$]	Graphic performance [3DMark]	Power consumption on mode [W]	[3DMark/W]
Hard disk drive (HDD), Solid state drive (SSD)	2009-2013 (HDD) 2008-2013 (SSD)	236 (HDD) 163 (SSD)	Street price [€$_{2010}$]	Capacity [TB], Input-Output (IO) performance [IO/s]	Power consumption on mode [W]	[W/TB], [IO/s,W]
Monitor	1999-2013	620	Street price [€$_{2010}$]	Screen area [dm^2], Resolution [megapixel]	Power consumption on mode [W]	[W/dm^2], [W/megapixel]
Network attached storage (NAS)	2004, 2006-2012	157	Street price [€$_{2010}$]	Capacity [GB], Transfer rate [MByte/s]	Power consumption on mode [W]	[W/TB], [MByte/s,W]
Notebook	2000-2013	461	Street price [€$_{2010}$]	Graphic performance [3DMark], Office processing [Cinebench (CB)]	Power consumption on mode [W]	[3DMark/W], [CB R1/W], [W/CB R11.5]
Power supply (internal)	2000-2006, 2008-2010, 2012, 2013	203	(Street) price [€$_{2010}$]	Rated power [W]	-	Average efficiency [%]
Printer (laser, inkjet)	2000-2010, 2012	318	Street price [€$_{2010}$]	Print speed for A4 black&white [pages per minute (ppm)]	Power consumption on mode [W]	[W/ppm]
Multifunctional Device (MFD) (laser, inkjet)	2002-2013	245	Street price [€$_{2010}$]	Print speed for A4 black&white [pages per minute (ppm)]	Power consumption on mode [W]	[W/ppm]
Projector	2002-2013	182	Street price [€$_{2010}$]	Brightness [lm], Resolution [megapixel]	Power consumption on mode [W]	[lm/W], [W/megapixel]
Router	2001, 2003, 2004, 2006-2012	290	Street price [€$_{2010}$]	Transfer speed WLAN [MBit/s]	Power consumption on mode [W]	[MBit/s,W]
Network switch	2003, 2006, 2007, 2009	67	Street price [€$_{2010}$]	Nr of ports	Power consumption on mode [W]	[W/port]
Streaming client (STC)	2003-2013	176	Street price [€$_{2010}$]	-	Power consumption on mode [W]	-
Set-top box	2001, 2002, 2004, 2006, 2008-2011, 2013	93	Street price [€$_{2010}$]	-	Power consumption on mode [W]	-
Television	2002-2012	177	Street price [€$_{2010}$]	Screen area [dm^2] Resolution [megapixel]	Power consumption on mode [W]	[W/dm^2] [W/megapixel]

[a] data for 2013 is for January-June

Product price is in almost all cases the ‘high street’ price, i.e. the actual price as found in (web) shops and includes purchase tax (VAT). The prices have been standardized to 2010 values by using harmonized indices of consumer prices (HICP) for Germany (Eurostat

2013). Prices of 1999, 2000 and 2001 were expressed in Deutsche Mark (DM) and converted to Euros by the DM to Euro conversion factor (1 Euro = 1.95583 DM).

The efficiency metrics used in this paper follow the conventions for the products. Although energy efficiency is the number of functional units (output) per unit of energy or power consumption, many conventional metrics used for efficiency of electronic products are in fact the inverse, e.g. power consumption per screen area expressed in W/dm2 for monitors and televisions. Note that in these cases a higher value indicates a lower efficiency.

In the following, an explanation is provided for some of the performance metrics. The performance of ***graphic cards*** has increased considerably over time and the performance metrics have changed to reflect this increase. c't uses several computer games to measure the frames per second (fps) performance of the card. However, to compare performance over a number of years, a more generic is needed; c't uses the 3DMark from Futuremark, an independent commercial benchmark software firm. This benchmark comes in different variants depending on the Direct X version that is used. Most performance data in the tests were (also) expressed by the 3DMark Vantage (preset: performance) benchmark. We converted all data expressed in other benchmarks to this benchmark. The collected data allowed this conversion because for many tests two or more benchmark figures were published and the correlation between the figures was good ($R^2 > 0.90$).

The c't dataset for ***computers*** contains data on three different types: main boards, bare bones (i.e. computers without CPU, memory, hard disk and disk drive) and (personal) computers. All products are tested as fully functional computers, e.g. for the test of bare bones the applicable CPU, memory, etc. is added. Analysis with respect to product price is carried out for the three subsets separately. To evaluate the performance of computers two different types of benchmarks are used: BAPCo SYSMark and 3DMark. The first is used to measure office performance and contains a suite of office programmes, including internet, word processing, spreadsheet, photo editing, and drawing. The second measures the graphic performance and is the same benchmark as used for graphic cards. Both performance metrics have evolved over time, the 3DMark to cope with increased graphic performance, the SYSMark to reflect changes in office programs over time. As for graphic cards, for many of the products tested the performance tests were published using two or more performance metrics. The correlation between the sets of figures from using the different metrics was good ($R^2 > 0.90$). We converted all graphic performance data to the 3DMark Vantage (preset: performance) benchmark. However, the SYSMark data was not converted since no conversion data was available. Although office programmes change over time, the nature of the work (word processing, using spreadsheets etc.) does not change. To calculate the graphic performance efficiency we used the maximum on-mode power and the 3DMark benchmark, to calculate the office processing efficiency we used the idle on-mode power consumption and the SYSMark benchmark.

For ***hard disks***, data were collected for hard disks with rotational storage medium (HDD) and solid state drives (SSD). The performance metrics are capacity in Gigabytes and the input-output (IO) performance. For HDD price data were available only for 56 of the 236 products.

For ***monitors***, only LCD (liquid crystal display) products were taken into account. c't have not published any tests on CRT (cathode ray tube) monitors since 2003.

Network attached storage (NAS) products came in two variants: delivered with and without hard disks. The latter means that the user has to buy (and install) the hard disks separately; the price of the product is without hard disks. Therefore, the analysis on the product price was done for the two variants separately.

To evaluate the performance of ***notebooks***, several benchmarks are used: 3DMark from Futuremark measuring graphic performance and Cinebench measuring CPU performance. Since 3DMark2003 data were available for almost all notebooks in the dataset, this benchmark was used in the analysis. Cinebench data came in two different variants reflecting the development in CPU performance over time. The results of Cinebench R11.5 (CB R11.5) could not be compared with previous versions like Cinebench 2003 R1 (CB R1), so a conversion was not possible. To calculate the graphic performance efficiency the power consumption when processing 3D images was used. To calculate the office performance efficiency the on-mode power consumption was used. Note that the choice of efficiency metric for the on-mode for both computers and notebooks differs from the approach taken by ENERGY STAR in that the most recent specifications uses a TEC (total energy consumption) metric, including off and sleep modes. However, this article focuses on the on-mode. Moreover, TEC values were only available for a limited number of years.

For ***internal computer power supplies*** a main performance parameter is the rated power. c't reported test data up to 2004 included the efficiency only at 80% load, from 2005 the efficiency was measured at 20%, 50% and 100% load. As efficiency metric up to 2004 the efficiency at 80% load was used, for the later years the average efficiency was used.

The main performance parameter for ***printers*** and ***multifunctional devices*** (printer, scanner and mostly fax) is the print speed for black and white A4. c't uses the document from the ISO 10561 standard (Grauert letter) for this test. However, the most recent (2013) tests use new documents from the ISO/IEC 24734 standard. Since no conversion factor was available for the print speed, these products were not included in the analyses.

For ***routers***, the WLAN transfer speed (in MBit/s) on short distance using the 2.4 GHz band was selected as the performance parameter since these data were available for most of the products. The power consumption for routers, streaming clients, and network switches is measured in on-idle mode, i.e. the product is fully functional but is not processing data. The reason is that this is a stable, and well defined, mode of which the power consumption can be used to compare products. Moreover, in many situations this will be the mode that the product spends most time in.

Set-top boxes in the data set were mostly satellite boxes (DVB-S), some cable boxes (DVB-C) or terrestrial boxes (DVB-S) and only two IP boxes. The data for set-top boxes and streaming clients contains no performance parameters.

For ***televisions***, data from 2002 onwards were available. However, the 2002 and 2003 models, 16 in total, were excluded from the analysis because these in general had a small screen size (15-17 inch) and could be considered more as computer monitors with a tuner than as televisions.

The aim of the data analysis is to investigate the relation between product price and efficiency. This is done in two steps. First, correlation analysis was employed to investigate the relationships between variables separately. Second, generalized linear model (GLM) analysis was used to investigate the relationship between efficiency and price, whilst also taking into account time (year) and performance. In addition, price developments over time of models with the same or comparable performance characteristics were investigated. Finally, the development of efficiency over time to prepare for an alternative approach to setting MEPS was explored.

5.3. Results

5.3.1. Results of the statistical analysis

This section describes the results of the analysis of 15 CE and ICT products. As a typical example, **Figure 5.1** shows the scatter plot of efficiency versus price for power supplies.

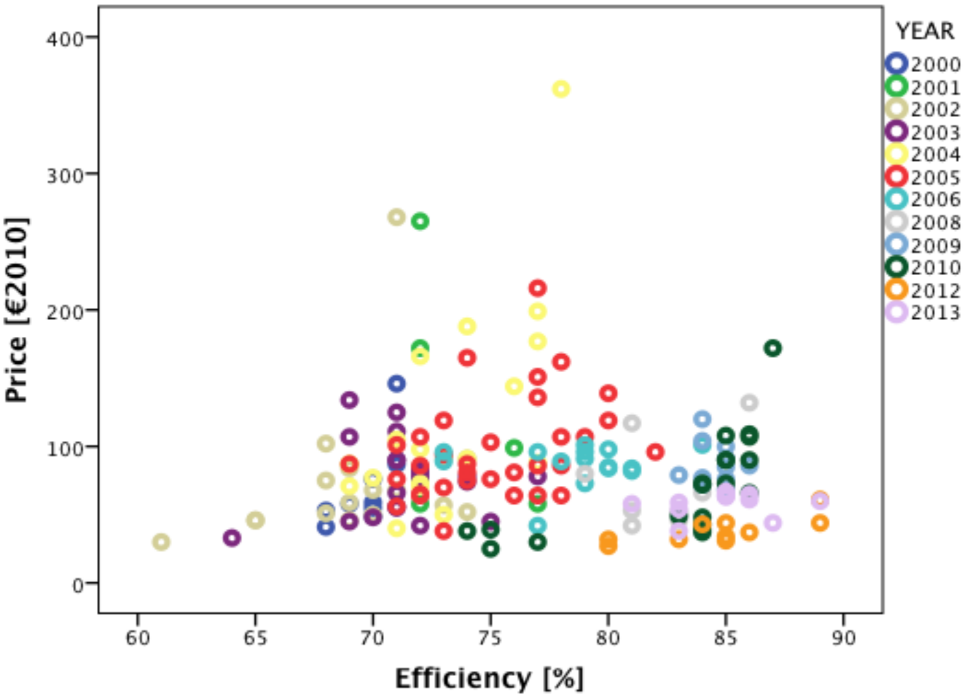

Figure 5.1 Price versus efficiency for power supplies (n=182)

At first sight this plot does not reveal a relationship between price and efficiency. However, we should take into account that price can also covariate with time and performance. As is shown later for selected products, the price of products with comparable performance decreases over time. Also, it is plausible that at a certain point in time, products with a higher performance can be more expensive. Furthermore, there are three possible interaction effects to take into account. First, the relation between performance and time: the performance of electronic products tends to increase over time. Second, the relationship between performance and efficiency: higher performing products tend to be more efficient. Third, the relationship between time and efficiency: products tend to become more efficient over time. **Table 5.3** shows the results of the correlation analysis between the variables separately, indicating that all of the relationships mentioned can be relevant. Since the distribution of the price data is not normal Spearman's rho was used as the correlation statistic. From the results of **Table 5.3** the following is noted. For all the significant correlations the price decreases with time. In general, the price increases with increasing performance, with the exception of monitors, projectors, and routers. Also efficiency increases with time for all products, with the notable exception of office performance efficiency of computers. For almost all products a medium or strong correlation between efficiency and performance is seen: higher performing products are more efficient. In general, performance has increased over time, again with the exception of the office performance of computers. This could be due to the change in the performance metric used, which has changed to follow the development of office software. Finally, we note that the Spearman's rho indicates whether or not two variables are related but does not indicate the magnitude of that relationship; whereas, the GLM analysis also provides the magnitude of the relationships.

Table 5.3 Results of correlation analysis

Product	**Efficiency parameter**	[a]	**PR-EFF**	**PR-YR**	**PR-PF**	**EFF-YR**	**EFF-PF**	**YR-PF**
PC	3DMark/W	+	-0.07	-0.21**	0.21**	0.75**	0.94**	0.63**
	SYSMark/W	+	0.18**		0.56**	-0.33**	0.29**	-0.18**
Bare bone	3DMark/W	+	0.09	-0.25**	0.13	0.08	0.90**	0.13
	SYSMark/W	+	0.10		0.12	-0.34**	0.60**	-0.38**
Main board	3DMark/W	+	-0.04	-0.51**	0.14	0.33**	0.95**	0.33**
	SYSMark/W	+	-0.08		0.27**	-0.36**	0.45**	-0.33**
Graphic card	3DMark/W	+	0.04	0.14	0.66**	0.83**	0.68**	0.74**
HDD	W/TB	-	-0.07	0.04	0.40**	-0.37**	-0.69**	0.44**
	IO/s,W	+	[b]		[b]	-0.11	0.19**	-0.08
SSD	W/TB	-	-0.61**	-0.30**	0.57**	-0.03	-0.68**	0.40**
	IO/s,W	+	0.27**		0.41**	0.17	0.69**	0.47**
Monitor	W/dm^2	-	0.73**	-0.68**	-0.29**	-0.75**	-0.52**	0.88**
	W/megapixel	-	0.68**		-0.17**	-0.74**	-0.46**	0.74**
NAS with HDD	W/TB	-	0.18	-0.11	0.25	-0.80**	-0.80**	0.81**
	MByte/s,W	+	-0.77*		-0.26	0.69**	0.70*	0.51**
NAS w/out HDD	W/TB	-	[b]	0.08	[b]	[b]	[b]	[b]
	MByte/s,W	+	-0.55**		0.04	0.82**	0.70**	0.66**
Notebook	3DMark/W	+	0.03	-0.43**	0.08	0.64**	0.90**	0.65**
	CBR1/W	+	0.17**		0.24**	-0.19**	0.17*	0.42**
	W/CBR11.5	-	-0.44**		0.73**	-0.60**	-0.70**	0.33**
Power supply	% eff	+	-0.02	-0.20**	0.27**	0.85**	0.60**	0.61**
Pinter (laser)	W/ppm	-	0.32**	-0.42**	-0.05	-0.51**	-0.46**	0.65**
Printer (inkjet)	W/ppm	-	0.28**	-0.31**	-0.08	-0.59**	-0.67**	0.71**
MFD (laser)	W/ppm	-	0.15	-0.35**	0.30**	0.10	-0.17	0.20
MFD (inkjet)	W/ppm	-	0.60**	-0.54**	-0.17*	-0.51**	-0.68**	0.47**
Projector	lm/W	+	-0.49**	-0.30**	-0.40**	0.27**	0.91**	0.46**
	W/megapixel	-	-0.25**		0.27**	-0.60**	-0.86**	0.71**
Router	MBit/s,W	+	-0.52**	-0.43**	-0.30**	0.76**	0.88**	0.75**
Network switch	W/port	-	0.41**	-0.29*	0.31*	-0.43**	-0.56**	-0.02
STC (audio)	-		na	-0.04	na	na	na	na
STC (video)	-		na	-0.33**	na	na	na	na
Set-top box	-		na	-0.56**	na	na	na	na
Television	W/dm^2	-	0.23**	-0.29**	0.21**	-0.91**	-0.73**	0.73**
	W/megapixel	-	0.55**		-0.08	-0.75**	-0.65**	0.84**

[a] +: higher values are more efficient, -: lower values are more efficient; PR: price; EFF: efficiency (see table 5.2); YR: year; PF: performance (see table 5.2); *: $p<0.05$; **: $p<0.01$; [b] n<20, not calculated; light grey: $0.30 \leq |r| < 0.70$; darker grey: $|r| \geq 0.70$; na: not applicable.

For the GLM analysis the model of **Figure 5.2** that includes the covariates, efficiency, year and performance, and the interaction effects described above is used.

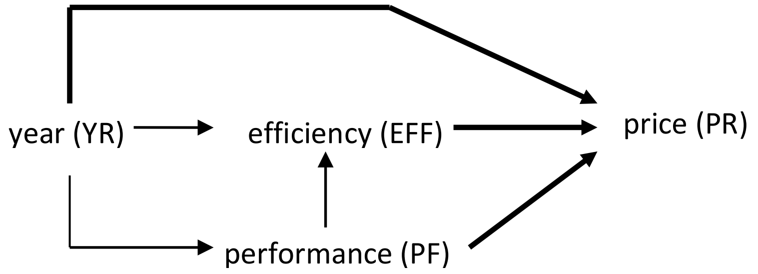

Figure 5.2 Model for analysis

Since the price variable has a gamma distribution, a GLM model with a log link function is used; the model equation then becomes:

$$\ln(\text{price})=C + \alpha_{EFF}\text{x}EFF + \alpha_{PF}\text{x}PF + \alpha_{YR}\text{x}YR + \alpha_{EFF,YR}\text{x}EFF\text{x}YR + \alpha_{EFF,PF}\text{x}EFF\text{x}PF + \alpha_{YR,PF}\text{x}YR\text{x}PF$$

with constant C. The analysis was restricted to products with n>100.

Table 5.4 explains the interpretation of the sign of the relationship between efficiency and price related to the sign of the efficiency parameter. When both signs are the same, this shows that a more efficient product has a higher price.

Table 5.4 Explanation of the efficiency parameter sign and the relation sign

		Sign relation efficiency-price	
		- (lower value, higher price)	+ (higher value, higher price)
Sign efficiency parameter	- (lower value, more efficient)	more efficient product, higher price	less efficient product, higher price
	+ (higher value, more efficient)	less efficient product, higher price	more efficient product, higher price

Table 5.5 provides the results of the GLM analyses. For one GLM analysis the likelihood ratio is not significant, i.e. the model of **Figure 5.2** does not provide better results than the constant C alone does. In 14 out of the 20 other cases, the coefficient (α_{EFF}) of the efficiency parameter is not significant. Where α_{EFF} is significant, it can be seen for three cases (efficiency of graphic cards, resolution efficiency of monitors and televisions) that a higher efficiency relates to a lower price. For three other cases (office performance

efficiency of PCs, efficiency of power supplies, and resolution efficiency of projectors) a higher efficiency relates to a higher price, indicated by the grey boxes in **Table 5.5**. These cases are now examined in more detail, including the relevance of the effect. With respect to the resolution efficiency of projectors we notice that the other direct effect, the effect of year on price, is larger than the effect of efficiency on price. An estimate of the relative magnitude of the effects can be obtained by multiplying the estimate of the coefficient with the mean value of the parameter(s). For EFF this results in 0.005x265=1.33 whereas for YR the value is 0.391x9=3.52. Although at a certain point in time a more efficient product will be more expensive, the price will quickly drop. With respect to the office performance efficiency of PCs it is also noticed that the direct effect EFF (0.792x1.2=0.95) is almost counterbalanced by the interaction effects EFFxYR (0.042x1.2x11=0.55) and EFFxPF (0.002x1.2x158=0.38). Furthermore, it can be seen that for PCs and projectors the other efficiency parameter is not related to the price.

Table 5.5 Results of generalized linear model analysis

Product	**Efficiency parameter**	[a]	n	***Likelihood ratio***	**Estimates of constant and coefficients**						
					C	α_{EFF}	α_{PF}	α_{YR}	$\alpha_{EFF,YR}$	$\alpha_{EFF,PF}$	$\alpha_{YR,PF}$
PC	3DMark/W	+	275	χ^2=139.5**	8.371**	0.022^{ns}	<0.001**	-0.153**	-0.001^{ns}	<0.001**	<0.001^{ns}
	SYSMark/W	+	321	χ^2=127.6**	6.131**	0.792**	0.04*	-0.028^{ns}	-0.042**	-0.002**	<0.001^{ns}
Bare bone	SYSMark/W	+	133	χ^2=16.4*	6.023*	0.830^{ns}	-0.005^{ns}	-0.086^{ns}	-0.081^{ns}	-0.001^{ns}	0.001^{ns}
Main board	3DMark/W	+	115	χ^2=12.2^{ns}							
	SYSMark/W	+	177	χ^2=48.4**	4.354**	-0.049^{ns}	0.010**	0.009^{ns}	0.032^{ns}	-0.002^{ns}	-0.001^{ns}
Graphic card	3DMark/W	+	139	χ^2=249.8**	7.803**	-0.029**	<0.001**	-0.327**	0.002**	<0.001^{ns}	<0.001**
SSD	W/TB	-	149	χ^2=201.7**	8.000**	0.041^{ns}	0.006^{ns}	-0.246**	-0.004^{ns}	<0.001^{ns}	<0.001^{ns}
	IO/s,W	**+**	107	χ^2=18.2^{ns}	5.966^{ns}	0.003^{ns}	-0.001^{ns}	-0.079^{ns}	<0.001^{ns}	<0.001^{ns}	<0.001^{ns}
Monitor	W/dm^2	-	616	χ^2=925.8**	6.545**	0.131^{ns}	0.046^{ns}	-0.171**	-0.035**	0.028**	0.003^{ns}
	W/megapixel	-	584	χ^2=920.3**	5.795**	0.040**	0.841**	-0.126**	-0.004**	0.010^{ns}	-0.009^{ns}
Notebook	3DMark/W	+	379	χ^2=202.6**	8.656**	0.002^{ns}	<0.001^{ns}	-0.192**	<0.001^{ns}	<0.001**	<0.001*
	CBR1/W	+	225	χ^2=148.9**	8.906**	0.011^{ns}	<0.001^{ns}	-0.326**	0.004^{ns}	<0.001**	<0.001*
	W/CBR11.5	-	153	χ^2=104.3**	7.092**	0.048^{ns}	-0.179^{ns}	-0.003^{ns}	-0.006^{ns}	0.014**	0.011^{ns}
Power supply	%	+	182	χ^2=90.9**	-3.976^{ns}	0.123**	0.006^{ns}	0.302^{ns}	-0.006**	<0.001^{ns}	<0.001^{ns}
Printer (laser)	W/ppm	-	174	χ^2=100.7**	7.702**	-0.019^{ns}	-0.076^{ns}	-0.195*	-0.004^{ns}	0.005*	0.005^{ns}
Printer (inkjet)	W/ppm	-	137	χ^2=39.5**	5.758**	-0.098^{ns}	0.123*	-0.256**	0.072**	-0.016*	<0.001^{ns}
MFD (inkjet)	W/ppm	-	143	χ^2=97.1**	6.069**	-0.094^{ns}	-0.054^{ns}	-0.159^{ns}	0.013^{ns}	0.045**	0.006^{ns}
Projector	lm/W	+	182	χ^2=95.5**	8.626**	0.053^{ns}	-0.001*	-0.002^{ns}	-0.049**	<0.001**	<0.001**
	W/megapixel	-	173	χ^2=187.9**	9.945**	-0.005**	-0.454^{ns}	-0.391**	<0.001^{ns}	0.004**	0.105**
Television	W/dm^2	-	161	χ^2=141.1**	9.204**	-0.033^{ns}	-0.029^{ns}	-0.305**	-0.010^{ns}	0.007**	0.004*
	W/megapixel	-	116	χ^2=131.9**	5.323**	0.013*	1.262*	-0.014^{ns}	-0.001^{ns}	0.006*	-0.065^{ns}

[a] +: higher values are more efficient, -: lower values are more efficient; PR: price; EFF: efficiency; YR=year-1998; PF: performance (see table 5.2); *: p<0.05; **: p<0.01; ns: not significant (p>0.05).

For power supplies, the efficiency effect is both significant and relevant, although in this case the interaction effect EFFxYR also reduces the impact. Each additional percentage point adds €$_{2010}$ 4 to the price, which is around 4% of the average product price. An explanation for the effect of efficiency on price can be that a power supply actually is usually a component and not a consumer product, and that costs are determined by material costs.

Table 5.5 illustrates two other general trends for electronic products. For all cases where the coefficient α_{PF} is significant a positive relation exists between price and performance: higher performing products are more expensive. Second, for all cases where α_{YR} is significant a negative relation exists between year and price: products become cheaper over time. For several products it is possible to follow price developments over time for models with the same or comparable performance, e.g. monitors with the same screen size. As an example, **Figure 5.3** shows the price of 23 inch monitors over time.

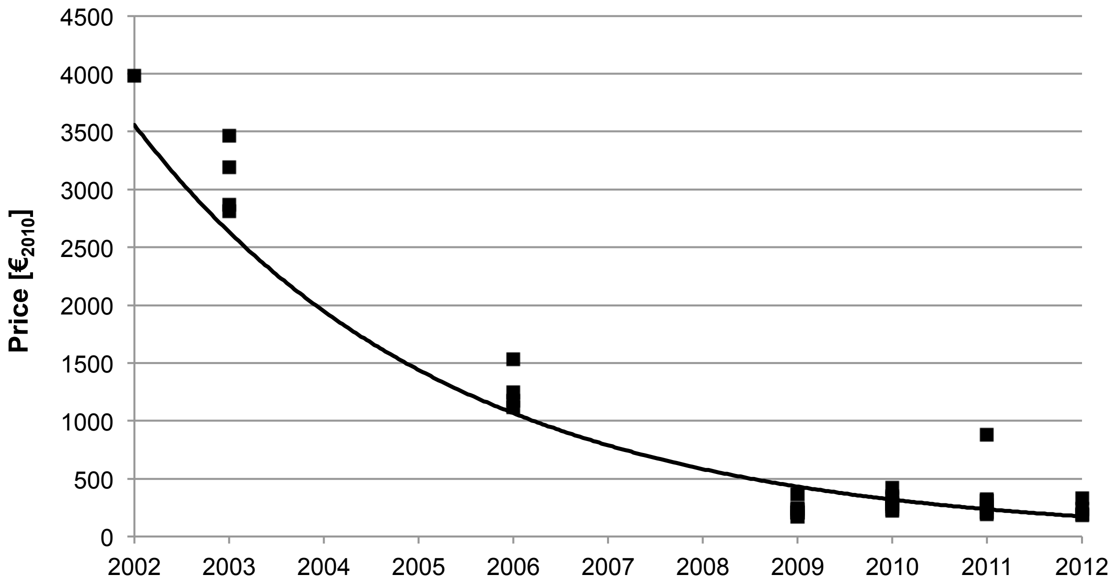

Figure 5.3 Price of 23 inch monitors (2002-2012) (n=44)

Table 5.6 shows the relation between price and time for several products with the same or comparable performance and the resulting price decrease per year. The products listed in **Table 5.6** show an exponentially decreasing price (price = p_0 e^{ct}) with time constant c = -0.30 on average (minimum: -0.17, maximum: -0.52). This means that on average, every year the product became 26% cheaper (minimum: 16%, maximum: 41%).

Table 5.6 Price development over time for selected products

Product	**Performance parameter**	**Development of price**		
		Type of fit	***Time constant c***	***Price decrease per year***
Graphic card	3DMarks≤5000	exponential (n=61)	-0.26(±0.04), R^2=0.391***	23%
	5000<3DMarks≤10000	exponential (n=30)	-0.36(±0.06), R^2=0.563***	30%
	10000<3DMarks≤15000	exponential (n=26)	-0.41(±0.04), R^2=0.821***	34%
SSD	120GB≤capacity≤128GB	exponential (n=58)	-0.35(±0.03), R^2=0.753***	30%
	240GB≤capacity≤256GB	exponential (n=47)	-0.32(±0.03), R^2=0.697***	27%
Monitor	screen size 15 inch	exponential (n=59)	-0.52(±0.05), R^2=0.667***	41%
	screen size 17 or 18 inch	exponential (n=130)	-0.43(±0.02), R^2=0.796***	35%
	screen size 19 or 20 inch	exponential (n=142)	-0.31(±0.02), R^2=0.637***	27%
	screen size 22 inch	exponential (n=73)	-0.20(±0.02), R^2=0.476***	18%
	screen size 23 inch	exponential (n=44)	-0.27(±0.02), R^2=0.772***	24%
	screen size 24 inch	exponential (n=85)	-0.26(±0.03), R^2=0.469***	23%
Router	WLAN transfer<30MB/s	exponential (n=81)	-0.21(±0.02), R^2=0.608***	19%
TV	screen size 30-32 inch	exponential (n=32)	-0.17(±0.04), R^2=0.420***	16%
	screen size 40 or 42 inch	exponential (n=51)	-0.30(±0.04), R^2=0.566***	26%

***: p<0.001

The results from the development of efficiency over time and the variation in efficiency are shown in **Table 5.7**. For most products the development of efficiency over time is described best by an exponential relation, for some products by a linear relation and for other products no (relevant) relation was found. The variation in efficiency is expressed by the coefficient of variation ($\sigma^2/\mu \times 100\%$). This coefficient was calculated for each year; the table shows the average over the years and standard deviation.

The results of the statistical analysis are summarised as follows. With respect to the relation between product price and efficiency, this is in most cases not significant or has the ‘wrong’ sign, meaning that the more efficient product is actually cheaper. In three cases the GLM analyses indicated that a higher efficiency was related to a higher price. However, only for internal power supplies for computers is the effect considered to be not only significant but also relevant: each additional efficiency percentage point adds €$_{2010}$ 4 to the price. The price of selected electronic products decreased exponentially over time with an average time constant of -0.30 per year, meaning products became 26% cheaper every year. Most products showed an improvement of efficiency over time, with the notable exceptions of solid state drives, laser MFDs and streaming clients. The results of the analysis triggered the development of an alternative approach to guide the setting of MEPS for electronic products, which is presented in the rest of this section.

Table 5.7 Development of efficiency over time; variation in efficiency

Product	**Efficiency parameter**	[a]	**Development of efficiency**		**Variation in efficiency**
			Type of fit	***Time constant c***	
Computer	3DMark/W	+	exponential (n=364)	0.32(±0.02), R^2=0.468***	avg: 90%, sd: 33%
	SYSMark/W	+	exponential (n=717)	-0.057(±0.005), R^2=0.165***	avg: 45%, sd: 10%
Graphic card	3DMark/W	+	exponential (n=139)	0.26(±0.02), R^2=0.686***	avg: 22%, sd: 10%
Hard disk drive	W/TB	-	exponential (n=229)	-0.29(±0.05), R^2=0.146***	avg: 71%, sd: 36%
	IO/s,W	+	no relevant development[c] in efficiency		avg: 57%, sd: 8%
Solid state drive	W/TB	-	no development[b] in efficiency		avg: 64%, sd: 20%
	IO/s,W	+	no relevant development[c] in efficiency		avg: 41%, sd: 20%
Monitor	W/dm^2	-	exponential (n=620)	-0.085(±0.003), R^2=0.567***	avg: 30%, sd: 8%
	W/megapixel	-	exponential (n=588)	-0.077(±0.003), R^2=0.548***	avg: 27%, sd: 7%
NAS	W/TB	-	exponential (n=74)	-0.38(±0.02), R^2=0.773***	avg: 56%, sd: 48%
	MByte/s,W	+	exponential (n=63)	0.30(±0.04), R^2=0.536***	avg: 48%, sd: 18%
Notebook	3DMark/W	+	exponential (n=385)	0.29(±0.02), R^2=0.497***	avg: 64%, sd: 26%
	CBR1/W	+	no development[b] in efficiency		avg: 35%, sd: 17%
	W/CBR11.5	-	exponential (n=154)	-0.25(±0.03), R^2=0.277***	avg: 40%, sd: 3%
Power supply	%	+	linear (n=202)	1.43(±0.06), R^2=0.725***	avg: 3.3%, sd: 1.2%
Printer (laser)	W/ppm	-	linear (n=174)	-1.3(±0.2), R^2=0.214***	avg: 28%, sd: 10%
Printer (inkjet)	W/ppm	-	exponential (n=137)	-0.11(±0.02), R^2=0.281***	avg: 45%, sd: 17%
MFD (laser)	W/ppm	-	no development[b] in efficiency		avg: 36%, sd: 20%
MFD (inkjet)	W/ppm	-	exponential (n=173)	-0.09(±0.01), R^2=0.359***	avg: 37%, sd: 19%
Projector	lm/W	+	no relevant development[c] in efficiency		avg: 32%, sd: 17%
	W/megapixel	-	exponential (n=620)	-0.085(±0.003), R^2=0.567***	avg: 22%, sd: 11%
Router	MBit/s,W	+	exponential (n=685)	0.29(±0.01), R^2=0.685***	avg: 44%, sd: 16%
STC (audio)	P_{on}	-	no development[b] in P_{on}		avg: 47%, sd: 33%
STC (video)	P_{on}	-	no development[b] in P_{on}		avg: 36%, sd: 15%
Network switch	W/port	-	linear (n=67)	-0.22(±0.04), R^2=0.364***	avg: 36%, sd: 11%
Set-top box	P_{on}	-	exponential (n=85)	-0.06(±0.01), R^2=0.177***	avg: 36%, sd: 15%
Television	W/dm^2	-	linear (n=161)	-0.62(±0.03), R^2=0.798***	avg: 22%, sd: 9%
	W/megapixel	-	linear (n=116)	-16.5(±1.2), R^2=0.630***	avg: 28%, sd: 17%

[a] +: higher values are more efficient, -: lower values are more efficient; ***: p<0.001; [b] model is not significant; [c] model is significant but R^2<0.1.

5.3.2. An approach for setting MEPS for electronic products

Introduction; selection of MEPS level

Basically, setting MEPS involves determining a point in the energy efficiency – time space, i.e. making a decision on both the MEPS level and the entry into force date. In this part of the results section we present a method for setting MEPS for products where there is no relation between energy efficiency and price. The selection of the MEPS level is guided by the variation in efficiency of the product. The selection of the entry into force date is guided by the price decrease. As with the LCC method, the guidance on the MEPS level and the entry into force date focuses on the consumer impact, i.e. the consumer should not be (financially) worse off. In the discussion in section 5.4 attention is paid to the impact on manufacturers. The application of the proposed method is limited by the following. First, for products where a relation between energy efficiency and price exists, the LCC method can be used. Second, if there is no improvement of average energy efficiency over time and no significant variation of efficiency exists in products on the market, an analysis of future technological developments is a more suitable alternative.

In general, three approaches can be distinguished for setting the MEPS level based on the variation in efficiency in products on the market:

- A minimum efficiency approach where the level is set to cut off around 20% of the market.
- An average efficiency approach where the level is set to cut off around 50% of the market.
- A maximum efficiency or top runner approach where the level is set to cut off around 80% of the market.

The choice for a certain approach depends, amongst others, on the ambition of the policy. Other factors that play a role are the expected future developments in efficiency of the product combined with the need to ensure sufficient competition. If there is little development expected then cutting off 80% of the market may result in less competition which can drive up prices. Also the choice for the target level can depend on complementary policy measures applied, e.g. an energy label. A mandatory MEPS is a relatively strong policy measure. Therefore, the option of a minimum efficiency approach in combination with an energy label may be preferred over a maximum efficiency approach only. Apart from the target level, the time that is needed to prepare for a policy measure should be taken into account. Therefore we first introduce the concept of the policy action window before discussing the selection of the entry into force date.

Policy action window

Product efficiency measures are taken in those situations where market forces alone do not, or not fast enough, achieve the desired policy objectives, in this case the improvement of energy efficiency. This means that the business as usual (BAU) rate of improvement, including the effect of policies already in force should be compared with the time needed for the (formal) procedure to set the MEPS levels. If the BAU development delivers the improvement faster, it might not be appropriate to set MEPS. The policy action window is proposed as an indicator of the time available for policy making and therefore an indicator of the appropriateness of setting mandatory MEPS. The policy action window (PAW) is defined as follows:

$$PAW = 2\ sd_{eff,avg}/EIC$$

where $sd_{eff,avg}$ is the average standard deviation of the efficiency over a number of years and EIC is the efficiency improvement coefficient, i.e. the average improvement of the efficiency over time. The policy action window is the time that is needed for the average efficiency to improve two times the average standard deviation or in other words, assuming a normal distribution, it is the time needed to improve more than 95% of the products. The definition of the policy action window implies that if there is no improvement in the average efficiency over time, i.e. EIC = 0, the policy action window becomes infinite. If the variation in efficiency is small and the improvement in efficiency is reasonable, the policy action window is very short. In this case the proposed procedure where the target is based on products available on the market may not be appropriate for setting MEPS. An analysis of future technological developments may be suitable alternative to base the target on. The concept of the policy action window is illustrated with the results for televisions; see **Figure 5.4**. The average standard deviation of the efficiency for televisions is 0.69 W/dm^2, the average efficiency improvement is 0.62 $W/(dm^2\ year)$. Thus, the policy action window is (2 x 0.69)/0.62 = 2.2 years. Since the development or revision of MEPS can easily take three years or more (Siderius 2013b), this immediately shows why the EU ecodesign requirements for televisions were considered to be obsolete when they came into force. However, **Figure 5.4** also shows that at the time of preparing the ecodesign measure, the improvement in efficiency in the period 2004-2007 was very small, resulting in a large policy action window.

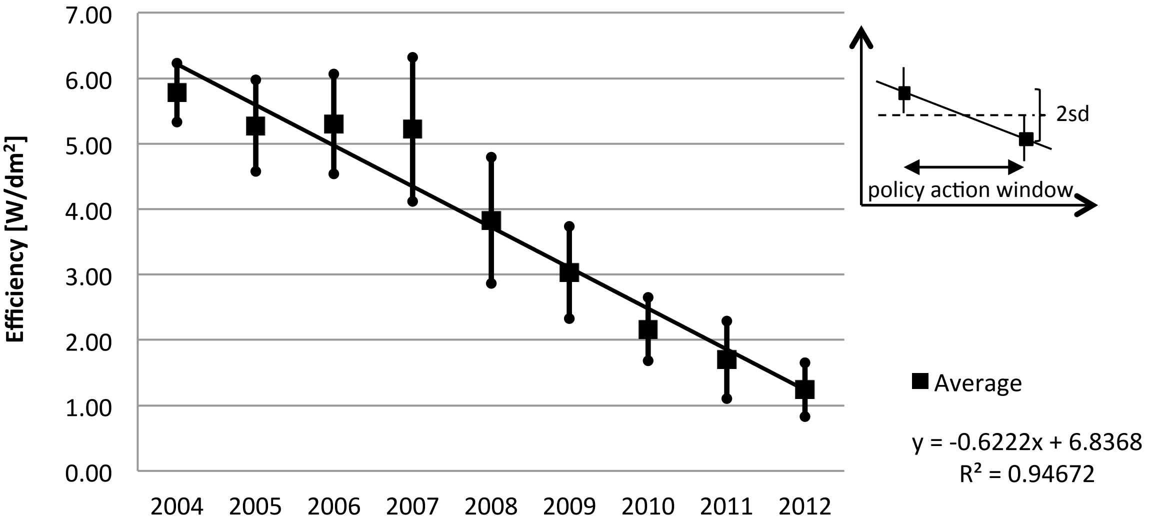

Figure 5.4 Efficiency improvement for televisions

Table 5.8 shows the values for the policy action windows for the products studied in this article. The policy action window varies considerably, indicating different opportunities for policy measures. Given the time necessary to prepare a measure, policy makers should be very cautious preparing measures for products with a PAW < 3 years.

Table 5.8 Policy action window (PAW)

Product	PAW [years]	Product	PAW [years]
Computer	5.2	MFD (laser)	15.5
Graphic card	1.7	MFD (inkjet)	14.2
Hard disk drive	7.1	Projector	24.9
Solid state drive	∞	Router	4.3
Monitor	7.5	STC (audio)	∞
NAS	2.8	STC (video)	∞
Notebook	5.3	Network switch	2.6
Power supply	3.1	Set-top box	9.2[a]
Printer (laser)	12.3	Television	2.2
Printer (inkjet)	9.7		

[a] based on P_{on}

Selection of the entry into force date

The method presented in this article is intended to be applied where there is no direct relation between price and efficiency. However, for some products a higher efficiency can be more easily achieved by higher performing products which cost more, certainly when recently introduced on the market. Also, as will be discussed in section 5.4, the date of entry into force needs to take into account the impact of the measure on manufacturers. Therefore, we propose that the average price decrease of the product guides the setting of the entry into force date, as follows. Calculate the average price p_{MEPS} of the products that remain on the market when applying the MEPS level (at the time of analysis T_0). This price should decrease to the average price of products p_0 on the market before applying the MEPS level. The reasoning is again that consumers do not need, on average, to pay more. Assuming that the price of the product decreases exponentially over time as shown in **Table 5.6** with time constant c, the entry into force date T_1 can be calculated by $T_1 – T_0 = - \ln(p_{MEPS}/p_0) / c$. The policy action window determines the latest date the MEPS can effectively come into force.

The following examples illustrate this approach. Although the data shows no development in the efficiency of SSDs over time and therefore the policy action window is infinite, the variation in efficiency is considerable. Assume that at T_0=2011 we want to apply an average efficiency approach cutting around 50% of the market. The average price in 2011 for SSDs is p_0= € 256. The average price of the remaining products on the market when applying the average efficiency approach is p_{MEPS}= € 362. From **Table 5.6** an average time constant for SSD of -0.34 is found. Now $T_1 – T_0 = - \ln(362/256)/-0.34 = 1.0$ year. In a second example, we want to apply at T_0=2010 the top runner approach to laser printers. The average price in 2010 for laser printers is p_0= € 336. The average price of the remaining products on the market when applying the top runner approach is p_{MEPS}= € 558. Furthermore, the price data for laser printers has a time constant c=-0.16. Now $T_1 – T_0 = - \ln(558/336)/-0.16 = 3.2$ year, which is well below the policy action window of 12.3 years for laser printers.

5.4. Discussion

In this section some aspects related to the methodology used, the results of the analysis and the alternative approach for setting MEPS developed in this article are discussed.

With respect to the ***methodology***, there are several observations. The analysis in this article was based on a limited dataset from a single source. However, since electronic products are fairly uniform and are globally traded goods, it can be argued that the statistical relationships and trends found are representative. This would likely be less true for any conclusions for absolute levels of the variables, especially the price. Also, the findings based on test methods employed by c’t may differ from those based on other test methods, e.g. for ENERGY STAR. However, any potential constant bias would be filtered out by the generalized linear model (GLM) analysis.

Another point is that we focused on the on-mode, whilst for several products energy consumption in other modes can be relevant. Power consumption in the off and standby modes has been regulated for several years, e.g. in the EU by Regulation 1275/2008[67]. Since all products have to fulfil these requirements, the variance in power consumption will be small and the costs – if any – will be about the same for all manufacturers. However, other modes like networked standby have not yet been regulated. For products where the total energy consumption (TEC) is used as a metric, an analysis for setting MEPS would need to take all components of this metric into account. In individual cases this could mean that modes, other than the on-mode, are more relevant.

The analysis showed that using simple correlations to assess the relation between price and efficiency can be misleading. **Table 5.3** shows for several products significant correlations between price and efficiency that are not present in the GLM analysis. On the other hand, for the single product – power supplies – where the relation between price and efficiency was found to be significant and relevant, the simple correlation between these variables was not significant. Only by using GLM analysis could the interaction effects be taken into account. The power supply example shows that the interaction effects can have a relevant impact: in this case it reduced the impact of efficiency on price by more than 40% on average. Still the GLM analysis, as used in this article, has its limitations. First, only one performance and related efficiency parameter was taken into account at a time, whereas in reality several performance parameters can play a role. However, the performance parameters taken into account were amongst the most important parameters as included in the c’t publications. Second, the model did not take into account other parameters that can influence the price, such as aesthetics, new features, the brand, or market structure. For the products covered in this article aesthetics play only a moderate role for certain products, e.g. televisions; and probably

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[67] OJ L 339, 18.12.2008, p. 45-52.

no role in main boards, graphic cards, HDDs, SDDs, NAS, internal power supplies, routers and network switches. New features may influence the price and this could mask a non-flat price-efficiency relationship. However, for this to happen, new features would need to systematically apply only to less efficient products so that the price increase due to new features would mask the price increase due to the better efficiency in the other products. As a general trend, this seems less likely because new features tend to come with new higher performing products that are generally more efficient. With respect to the brand, the number of models per brand was too small to analyse the impact in any meaningful way. This is due to the fact that the c’t tests only contained a few models per brand. Furthermore, over the period studied, brands merged, appeared and disappeared from the market. In order to have a masking effect in the GLM analysis, a brand would have to have less efficient products that have the same price as more efficient products from another brand. As a general rule this seems less likely because less efficient products tend to have lower performance and performance is a key aspect in CE and ICT markets. With respect to market structure in general CE and ICT, markets enjoy fierce competition that is illustrated by the exponential price decrease. Therefore, it is unlikely that systematically monopolistic control of market share has occurred that would have changed the results.

Finally, the example of performance for computers showed that consistency in performance metrics is important, including being able to relate the new metric to the old one. This is especially challenging for performance parameters that evolve rapidly as was shown by the metrics on graphic performance for computers and notebooks.

With respect to the ***analysis of the results***, we found three general trends: price does not relate to efficiency, higher performing products are more expensive, and products become cheaper over time. Due to the limited space of the article, these trends are not explained in detail, and understanding the possible causes of these trends, would have required additional and different types of research. Nevertheless, some suggestions that can be investigated in further research on this topic are provided. Increasing performance due to technological developments seems to be the driver for several trends. For integrated circuits (ICs) the performance or capacity doubles roughly every two to three years. Furthermore, continued improvement in manufacturing process technology also plays a role. Each generation of manufacturing lines gives a better yield: more useful LCD panels, more functioning ICs. This reduces the cost per panel or IC. Increased performance also drives efficiency. In order for the power consumption to stay within limits, increasing performance can only be achieved by increasing efficiency. Not only notebooks that run on batteries, but also graphic cards have a power limit; in the latter case this is the power that the power supply of the computer can deliver for the card and its cooling. Improving efficiency also improves the reliability of products since less heat is produced.

Higher performing products are more expensive and the highest performing products are much more expensive. First, because manufacturers need to recover the product development costs and investment costs in new production lines (cost factor). Second, because manufacturers can ask a price premium for exclusive products (marketing factor). Since the analysis was done on price – as no data on cost was available - it was not possible to decompose the price difference into the cost and marketing factor.

The trend that products become cheaper over time is a result of both competition and increasing performance. A frontrunner introduces a new, higher performing product and can ask a higher price for this product. Competitors enter the market with products with the same, or even higher, performance and the price drops. Even if there would be no competition, when a better performing product is offered it is likely that the older, less performing product can not be sold at the same price. For this to occur the new product would need to be sold at a higher price and with further product development this would mean that at some point the product would be out of the price range that is acceptable for consumers.

The results of the analysis suggest that the classical approach of setting MEPS by means of LCC calculations should not be applied to electronic products. Since LCC calculations also include an assessment of the ***impact of a measure on manufacturers***, we discuss how this impact can be taken into account when applying the alternative presented in this article. Costs are important for manufacturers because, given a certain price, higher costs mean less profit. However, a pure cost assessment to address the impact on manufacturers does not seem suitable and realizable. As indicated above, cost data, certainly regarding new developments, is mostly confidential, or in other words the information on costs is highly asymmetrical: manufacturers have the information, policy makers do not. Furthermore, the attribution of costs poses a problem. Are costs for redesign and re-tooling to be attributed to the improvement of efficiency or is the redesign scheduled anyway? Is the extra cost for a certain component to be attributed to efficiency improvement or to better performance or design? Finally, costs are not static but highly dynamic. Costs for low production volume components, e.g. only applied in high-end products, can be considerable, but with increasing volume of production costs quickly fall. Because for electronic products time literally means money, the selection of the entry into force date of a measure seems to be a good way to take the impact of the measure on manufacturers into account. However, it does not replace a full manufacturers' impact analysis. Looking at the three options presented for setting MEPS, the minimum efficiency approach probably requires only minor changes which in general could be absorbed in a year. On the other hand, the top runner approach might result in a complete redesign of a platform, the basic design on which a (large) number of models is based, which also for electronic products can take several years. The average efficiency approach probably ends up in between. The mechanism that certain efficiency improvements are introduced in high-end products first and then trickle down is accounted for by using the (average) price decrease to guide the entry into force date.

The ***alternative approach for setting MEPS*** heavily depends upon historical data. Although this is no exception, see e.g. Blum et al. (2013), experience with the ecodesign MEPS process in the EU shows that for many products collecting historical data is not an easy task. However, ecodesign measures include requirements for manufacturers to provide data on public websites. In other countries, e.g. US and Australia, mandatory product registration is part of the measure, so data for the review of measures is available.

Furthermore, electronic products are well known for new developments, new features and new functions which might need more power. Sometimes, new features can be ignored because they will be used only seldom or a small part of the time. Trying to take the development of new functions into account has several consequences. First, metrics might need to be updated which can lead to loss of consistency between the old and new metrics as a result. Since the proposed approach depends upon the availability of time series data for e.g. establishing the policy action window, guidance for measures based on the new metric is still delivered by evidence based on the old metric. Second, the ultimate goal of product efficiency policy is to reduce energy consumption. Including new features into the efficiency equation might result in a better efficiency for the product, but not in reduced energy consumption. Also, it can be difficult to decide on a ‘power budget’ for features, knowing that after a certain time the power consumption is negligible because the feature is integrated.

The proposed approach does not make technical analysis superfluous. It still can be useful to investigate whether options for efficiency improvements exist that are not already applied to products on the market. The proposed approach bases the MEPS on values already achieved by products on the market. In situations where the variance in efficiency is small and developments are slow, assessing long term developments can indicate the efficiency improvements beyond the variance found in products on the market.

5.5. Conclusions and policy implications

When analysing price, performance and efficiency data for 15 CE and ICT products, it was found that in general the price did not relate to the efficiency of the product. An exception was the internal power supply for computers where each additional efficiency percentage point added $€_{2010}$ 4 to the price. Furthermore, the price of electronic products with comparable performance characteristics decreased over time. For products where the data allowed fitting the relation, an exponential decrease with an average time constant of -0.30 per year was found, meaning that every year the product became 26% cheaper.

The results imply that the classical approach of setting MEPS by means of life cycle cost (LCC) calculations alone cannot be applied to the products analysed in this article, because for these products no relation exists between product price and efficiency. The product price seems to be related to (performance) features and especially the newness of the product. High prices are asked for new products with high performance features. Once on the market, the price of these products will decrease (exponentially) until they are superseded by new products with improved functionality or new features.

We presented an alternative approach based upon variation in efficiency of products on the market and improvement of efficiency over time. It is proposed that the average price decrease of the product should guide the entry into force date of the measure, taking into account the desired level of ambition. The proposed approach gives policy makers a tool to set MEPS without the need of using cost data which is frequently difficult to obtain.

The concept of the policy action window provides guidance for the decision whether setting MEPS for a certain product is appropriate. If the (formal) procedure for setting MEPS takes longer than the policy action window, it means that the efficiency improvement will also be achieved without setting MEPS unless efforts are made to shorten the procedure. We found short, i.e. less than three year, policy action windows for graphic cards, network attached storage products, network switches, and televisions.

The policy action window proposed in this article can be used for priority setting, together with data on the variance in efficiency of a product. Products with a large policy action window and a large variance have a large improvement potential that probably will not be realized without appropriate measures. Assuming their total energy consumption is significant, these products could be prioritized for energy efficiency measures. On the other hand, and given the time needed to prepare policy measures, policy makers should be cautious in preparing measures for products with a policy action window shorter than three years, unless of course other arguments exist.

Annex: Descriptive statistics

Product	Variable	Unit	^{a}	n	min	max	mean	stdev
PC	Price	€$_{2010}$		409	146	11245	1206	1284
	Graphic eff	3DMark/W	+	277	<0.01	126	21	26
	Office eff	SYSMark/W	+	329	0.3	5.2	1.3	0.7
	Graphic perf	3DMark		288	1	37091	4451	7190
	Office perf	SYSMark		341	21	385	155	72
Bare bone	Price	€$_{2010}$		144	69	2421	358	289
	Graphic eff	3DMark/W	+	61	<0.01	75	2.8	10
	Office eff	SYSMark/W	+	139	0.8	4.3	1.8	0.6
	Graphic perf	3DMark		62	<0.01	2927	231	598
	Office perf	SYSMark		142	46	320	205	67
Main board	Price	€$_{2010}$		383	53	1463	187	156
	Graphic eff	3DMark/W	+	115	<0.01	83	9.0	12
	Office eff	SYSMark/W	+	182	0.4	4.2	1.4	0.6
	Graphic perf	3DMark		117	4	6239	1643	2090
	Office perf	SYSMark		214	24	361	197	65
Graphic card	Price	€$_{2010}$		139	30	495	184	125
	Efficiency	3DMark/W	+	139	21	317	93	56
	Performance	3DMark		139	538	28881	8331	7624
HDD	Price	€$_{2010}$		56	38	330	120	61
	Capacity eff	W/TB	-	229	2	168	11	14
	IO eff	IO/s,W	+	181	5	85	31	17
	Capacity	GB		233	75	4000	996	964
	IO perf	IO/s		185	34	447	139	74
SSD	Price	€$_{2010}$		155	30	1616	265	202
	Capacity eff	W/TB	-	156	3.5	175	20	18
	IO eff	IO/s,W	+	111	42	7280	3016	1447
	Capacity	GB		162	8	800	171	120
	IO perf	IO/s		115	75	17499	8077	4405
Monitor	Price	€$_{2010}$		616	121	6125	994	1083
	Screen eff	W/dm^2	-	620	0.64	7.34	2.59	1.11
	Resolution eff	W/megapixel	-	588	3.9	46.4	17.9	7.3
	Screen area	dm^2		620	6.2	25.7	12.2	4.4
	Resolution	megapixel		588	0.79	4.10	1.75	0.66
NAS with HDD	Price	€$_{2010}$		61	98	3951	691	700
	Capacity eff	W/TB	-	60	4	123	43	31
	Transfer eff	MByte/s,W	+	27	<0.01	2.5	0.8	0.7
	Capacity	GB		61	80	12000	1441	1876
	Transfer rate	MByte/s		27	3.3	84	20	16
NAS w/out HDD	Price	€$_{2010}$		81	53	1618	403	321
	Capacity eff	W/TB	-	15	<0.01	97	13	24
	Transfer eff	MByte/s,W	+	37	0.1	1.8	0.8	0.5
	Capacity	GB		15	120	12000	5521	3948
	Transfer rate	MByte/s		37	6.1	70	27	14
Notebook	Price	€$_{2010}$		455	263	6173	1424	957
	Graphic eff	3DMark/W	+	385	2	568	172	124
	Office eff	CB R1/W	+	229	2	59	11	7
	Office eff	W/CB R11.5	-	154	2	69	22	12
	Graphic perf	3DMark		419	66	38885	8165	8726
	Office perf	CB R1		264	46	715	318	140
	Office perf	CB R11.5		160	0.2	20.7	2.4	1.9
Power supply	Price	€$_{2010}$		184	25	362	83	45
	Efficiency	%	+	202	61	89	77	6
	Rated power	W		202	180	850	421	134
Pinter (laser)	Price	€$_{2010}$		181	59	7914	1230	1513
	Efficiency	W/ppm	-	174	6.6	70.8	28.6	9.7
	Print speed	ppm		174	6.2	27.3	14.9	4.9
Printer (inkjet)	Price	€$_{2010}$		137	42	1657	298	282
	Efficiency	W/ppm	-	137	0.5	31.7	2.7	3.2
	Print speed	ppm		137	1.3	33.3	7.7	4.3
MFD (laser)	Price	€$_{2010}$		76	76	3056	845	494

Product	**Variable**	**Unit**	[a]	**n**	**min**	**max**	**mean**	**stdev**
	Efficiency	W/ppm	-	72	2.8	80.2	26.5	11.4
	Print speed	ppm		72	7.3	25.0	14.9	4.6
MFD (inkjet)	Price	€$_{2010}$		163	63	1165	252	182
	Efficiency	W/ppm	-	156	0.8	8.6	2.0	1.3
	Print speed	ppm		160	1.4	20	11.1	3.8
Projector	Price	€$_{2010}$		182	106	9372	1940	1577
	Brightness eff	lm/W	+	182	0.9	11.8	5.2	2.5
	Resolution eff	W/megapixel	-	173	87	600	265	113
	Brightness	lm		182	161	3185	1243	716
	Resolution	megapixel		173	0.41	2.07	1.12	0.62
Router	Price	€$_{2010}$		284	9	1290	238	235
	Transfer eff	MBit/s,W	+	205	0.2	35	9.9	8.0
	Transfer speed	MBit/s		208	1.2	257	61	47
Network switch	Price	€$_{2010}$		67	47	1486	311	218
	Power per port	W/port	-	67	0.4	4.7	1.5	0.9
	Nr of ports			67	8	28	15	7.9
STC (audio)	Price	€$_{2010}$		76	78	2495	330	375
	P_{on}	W		76	2.7	33	8.2	5.8
STC (video)	Price	€$_{2010}$		99	66	2586	238	257
	P_{on}	W		82	3.6	61.2	11.2	7.7
Set-top box	Price	€$_{2010}$		89	105	1767	535	331
	P_{on}	W		85	2.6	75.5	22	9.8
Television	Price	€$_{2010}$		161	200	7641	1374	1032
	Screen eff	W/dm^2	-	161	0.8	6.8	3.3	1.7
	Resolution eff	W/megapixel	-	116	15	199	82	42
	Screen area	dm^2		161	10.4	83.0	39.4	17.6
	Resolution	megapixel		116	0.31	8.29	1.67	0.82

eff: efficiency; perf: performance; [a]: +: higher values are more efficient, -: lower values are more efficient

6.

Analyzing delays in preparing and adopting ecodesign and energy label measures[68]

Abstract

The ecodesign and energy labelling directives are important parts of EU energy efficiency policy and delayed measures result in less energy savings. Therefore the duration of preparing and adopting measures is an important aspect of effectiveness. With an average duration of 71 months none of the 12 published measures since 2010 met the planning suggested by the Commission. We identified the following reasons for the delays: the process organization and capacity at the Commission was not matching the workload; low quality of some of the preparatory studies and lack of data for some products; and technical complexity and political sensitivity.

Comparing ecodesign (with comitology) and energy labelling (without comitology) we found that comitology provides a more transparent process, secures Member State expertise that is necessary to deal with highly complex and technically detailed legislation, is less vulnerable to single interest lobby and therefore less likely to cause delays.

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[68] Earlier versions of this chapter were presented at the eceee 2013 Summer Study and the conference In Search of European Political Union (19-21 June 2014).

6.1. **Introduction**

EU (European Union) law making is a complex and challenging process. Improving this process has been on the agenda of the European institutions since a long time (Voermans 2009); see e.g. the website of the European Commission ec.europa.eu/smart-regulation that is devoted to this subject. Most EU legislation is lower level, secondary legislation. The Commission processes 80 % of EU directives, decisions and regulations of which 46 % through comitology (Brandsma 2013, p. 22-23). Although the Lisbon Treaty changed the scene for comitology (Peers and Costa 2012) it still plays and will continue to play an important role in lower level EU rule making. Comitology has been studied intensively (see overview of Blom-Hansen (2011)) regarding accountability, openness and participation or more general regarding the (lack of) democratic legitimacy. More specifically, part of the critique on comitology refers to comitology being ‘misused’ to devalue the role of the European Parliament (EP) in the legislative process. This reflects both the fact that committees are made up of Member State experts with no involvement of the EP and the possibility that the implementation process through a committee could substantially modify the intended effect of the original legislation (Neuhold 2008). Another line of critique refers to the lack of openness and transparency of the committees, i.e. the limited availability of documents prior to meetings, the fact that committee meetings are behind closed doors and the poor quality of the summary records of the meetings (Neuhold 2008, Brandsma et al. 2008).

In this chapter we pay attention to another aspect of lower level law making in the EU, the duration of law making. This can be seen as an important aspect of effectiveness; unduly delayed measures are less effective. Certainly this holds for the policy area that is the topic of this thesis, product energy efficiency, where delayed measures result in less energy savings. For example, the measures for boilers and water heaters were more than 3 years delayed compared to the original planning. With an estimated primary energy savings of 2350 PJ per year for the EU this amounts to more than 7000 PJ of missed cumulative savings, which is about the annual gross inland energy consumption of Italy in 2011 (European Commission 2013, p. 186). Furthermore, regarding comitology, the preparation and adoption of measures for the same products in parallel under the

Ecodesign directive 2009/125/EC[69] and Energy labelling directive 2010/30/EU[70] provides an opportunity to look 'in and out' of comitology. The Ecodesign directive is a pre-Lisbon directive and includes a Regulatory Committee whereas the Energy labeling directive is a post-Lisbon directive with delegated acts and therefore without committee. In both directives consultation of stakeholders is done through meetings of a Consultation Forum.

The aim of this chapter is to investigate and explain delays in lower level law making for product energy efficiency as an aspect of effectiveness and to investigate in practice the difference between lower law making with and without comitology.

This chapter is structured as follows. In the next section we introduce the Ecodesign and Energy labeling Directives as important parts of EU energy efficiency policy and describe the process of preparing and adopting executive measures under these directives. Section 6.3 shortly describes the methodology of the data collection. Section 6.4 presents results of the analysis, including explanations for the delays, quantification of the delay factors and impacts on energy savings. It also describes experiences with measures developed 'in and out' of comitology. In section 6.5 we describe the process for setting MEPS in the US and Japan and extract lessons learned. Finally in section 6.6 we discuss the findings and provide recommendations for the process and a view on comitology.

6.2. **Preparing and adopting ecodesign and energy labelling measures**

Ecodesign and Energy labeling Directives are an important part of EU energy efficiency policy; see the Energy Efficiency Plan (European Commission 2011a). The Ecodesign Directive aims to set requirements to significant environmental aspects of energy-related products, i.e. products that have an impact on energy consumption during use. For all products regulated so far energy consumption during the use phase has been the main or at least one of the main environmental aspects. Therefore ecodesign can be seen as the EU way to set minimum efficiency performance standards (MEPS) for products, comparable with the Department of Energy appliance standards in the US. The Energy labeling Directive aims to provide information through energy labels and product information thereby allowing end-users to choose more efficient products. Although the

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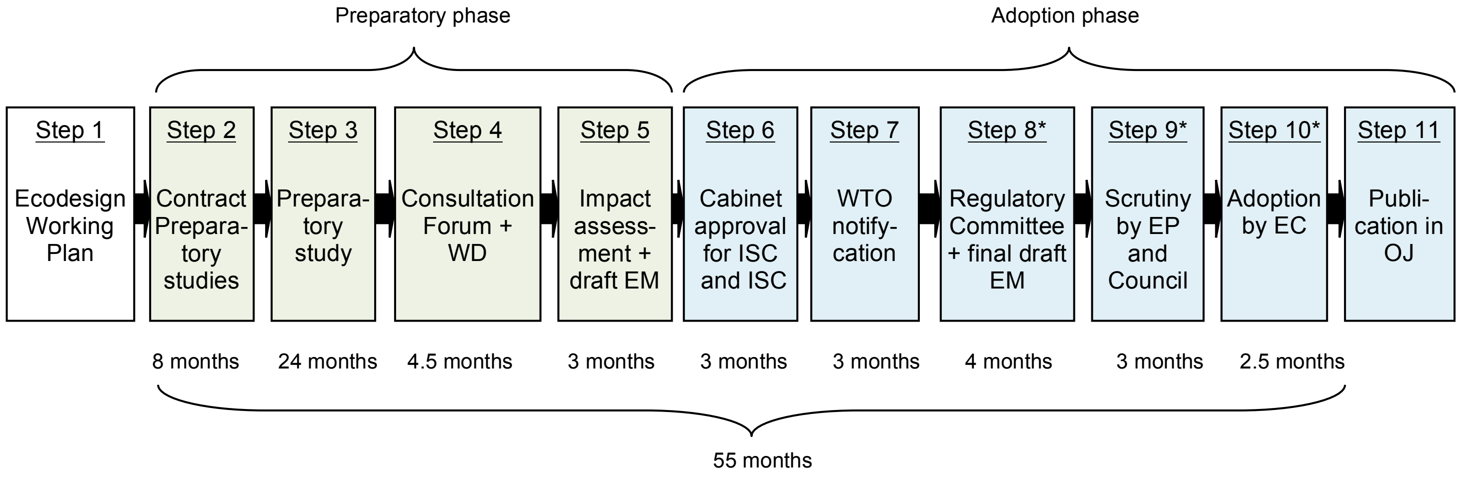
[69] OJ L 285, 31.10.2009, p. 10-35.

[70] OJ L 153, 18.6.2010, p. 1-12.

scope of the Energy labeling Directive is the same as the Ecodesign Directive, energy-related products, in practice so far energy labels have only been adopted for consumer products (white goods, lighting, air conditioners, televisions). Both directives are framework directives; they do not directly set requirements or labels for products but provide the criteria and procedures to adopt measures which contain the requirements or the label design including the label classes. In both cases the measures are regulations and thereby directly applicable in the Member States thus ensuring a level playing field for manufacturers.

The process of preparing and adopting measures follows from directions in primary EU law, the directives and internal Commission procedures. According to **Figure 6.1** the Commission (European Commission 2012b) estimates the total process time to be 55 months or about 4.5 years. For this chapter we define delays as positive deviations from the process times in figure 1, i.e. the duration in reality is longer than the duration indicated in **Figure 6.1**[71].



WD: working document; EM: executive measure; ISC: InterService Consultation; WTO: World Trade Organization; EP: European Parliament; EC: European Commission; OJ: Official Journal

*Regarding energy labeling executive measures, step 8 is not applicable and step 9 and 10 are exchanged, i.e. first the measure is adopted by the Commission and then it is sent to the European Parliament and Council for scrutiny.

Figure 6.1 Ecodesign process

The Ecodesign Directive has been recast in 2009; **Figure 6.1** reflects the situation after the recast. In the process before 2009 some of the steps were shorter in duration, e.g. the

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[71] The word ‘delay’ can have a negative connotation. Several of the interviewed experts noted that the process needs the time it takes, in other words in their view delays do not exist. Although we later look at ways to shorten the duration of the different steps, for the analysis the concept of delay does not include a value judgement.

preparatory study (step 3) and the scrutiny by EP and Council (step 9). Altogether, the process of the first measures (adopted in 2008 and 2009) should not be compared with the process in **Figure 6.1** but with a process that is about 18 months shorter, so in total 37 months. In reality, as we show below, since 2010 none of the accepted measures have met this planning, nor will probably any of the measures that are now being prepared. As of October 1st 2013 regulations have been published for 22 products: 22 ecodesign regulations and 10 energy labelling regulations. Measures are being prepared for at least another 19 products.

Since the ‘comitology’ step (step 8 in **Figure 6.1**) is an important step in the process and the main difference between the process for ecodesign and energy labelling measures, we provide a short explanation of comitology. Comitology refers to the system of committees, consisting of Member State experts, that assist the European Commission in its secondary rule making (Brandsma 2010, p. 30-34). This means the following. First, secondary rules refer to the measures that are adopted under basic legislation adopted by the Council and the European Parliament (in case of co-decision). The adoption of these secondary rules is delegated by the basic legislation to the Commission. Second, although sometimes the term comitology is also used for Council working parties or expert groups, this is formally not correct because these groups either do not assist the Commission or are not concerned with secondary rules. Comitology refers to committees that work under the regime of the Comitology Decision[72] (pre-Lisbon) or under the Implementing Act Regulation[73] (post-Lisbon). Third, the assistance to the Commission comes with various levels of influence. The Comitology Decision provides for three types of committees (advisory, management and regulatory), the Implementing Act Regulation for two (advisory and examination). Advisory committees have - as the name indicates – an advisory role: although the Commission shall take the utmost account of the opinion delivered by the committee, the measure adopted by the Commission can deviate from the opinion of the committee without further procedural consequences. In case of a management, regulatory or examination committee, the Commission may only adopt measures if these are in accordance with the opinion of the committee. The opinion of

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[72] OJ L 200, 22.7.2006, p. 11-13, amending OJ L 184, 17.7.1999, p. 23-26.
[73] OJ L 55, 28.2.2011, p. 13-18.

the committee shall be delivered by a qualified majority. If the opinion of the committee is not in accordance with the measure proposed by the Commission, the further process requires involvement of the Council and the European Parliament. In practice the management, regulatory or examination procedure means that the committee fixes the text of the measure that than has to be adopted by the Commission. Furthermore, if the Commission during the discussions in the committee finds that the (amended) text will not get a qualified majority, it will not bring the text to a vote.

6.3. **Methodology**

In the research for this chapter both quantitative and qualitative methods have been used.

The following quantitative data has been available for the analysis (see Annex), all of which can been found in publicly available documents (see http://ec.europa.eu/energy/efficiency/labelling/household_en.htm and http://eur-lex.europa.eu/en/index.htm for the text of published regulations): start and end date (in months) of the preparatory study, date of the Consultation Forum (CF) meeting(s), date of the vote in the Regulatory Committee (RC), date of adoption by the European Commission and date of publication in de Official Journal. The start and end of the impact assessment (step 5), the interservice consultation (step 6) and the WTO notification (step 7) are not generally known. Only recently the Commission started to inform Member State experts and other stakeholders about the start of these activities but for the majority of the measures these dates are not available. From the available data the following time periods can be calculated (see Annex for data):

- Total duration (D_T): from the start date of the preparatory study (step 3) until the date of publication in the Official Journal.
- Duration since (first) Consultation Forum meeting (D_{CF}): from the date of the first Consultation Forum meeting until the date of publication in the Official Journal.
- Duration since Regulatory Committee meeting (D_{RC}): from the date of the meeting of the Regulatory Committee until the publication in the Official Journal.
- Duration of the preparatory study (D_3): from the start date until the end date of the preparatory study.

- Duration of the Consultation Forum phase (D_4): from two months before the (first) Consultation Forum meeting until two months after the (last) Consultation Forum meeting.
- Time between the end of the preparatory study and the start of step 4 (D_{3-4}): from the end date of the preparatory study phase until two months before the (first) Consultation Forum meeting.
- Time between the end of step 4 and the Regulatory Committee meeting (D_{4-8}): from two months after the (last) Consultation Forum meeting until the date of the Regulatory Committee meeting.

Furthermore, for this chapter 30 experts from Member States, industry, NGOs and Commission have been asked to score the products for which a measure has been published or is being prepared on the quality of the preparatory study and the technical complexity and political sensitivity of the product (see Annex for average scores). The experts were selected from the participants in the Consultation Forum meetings and had at least several years of experience with various ecodesign and energy labelling measures and EU legislation. Answers were received from 22 persons, covering all stakeholder categories mentioned. The respondents scored the products and aspects they had been involved in; the average number of answers for technical complexity and political sensitivity was 14,5 and 8,7 for the quality of the preparatory study. This indicates that the respondents had been less involved in the preparatory studies.

Qualitative research methods used were participation in the various processes, reading of documents (minutes of meetings, studies, working documents, etc.) and semi-structured interviews with key stakeholders from the categories mentioned (n=9). The respondents were a subset of the experts that were asked to score the products.

6.4. **Results**

In this section we provide the results of the analysis. First we present the results on process time and the delays in the various steps of the process. Second we present the results of the analysis of the various steps in the process of **Figure 6.1** with emphasis on finding possible causes for delays. Third we present the delay factors in more detail especially the product related factors complexity and political sensitivity, and try to quantify the impact on process time and energy savings. Finally we focus on the differences between the ecodesign and energy labeling process (in and out of comitology); based only on the results of the interviews.

6.4.1. Process time and delays: quantitative results

Table 6.1 shows process time data for all products (N=41) and for products for which measures have been published in the Official Journal (N=22). From the 10 measures published in 2008 and 2009, 5 met the planning according to **Figure 6.1** whereas from the 12 measures published from 2010 onwards none met the planning according to **Figure 6.1**.

Table 6.1 Process time data

	Norm (see fig. 1)	Average [months]	St.dev. [months]	Coefficient of variation
All products (N=41)				
D_3: duration preparatory study (step 3)	24	23	7	0.3
D_4: duration Consultation Forum (step 4)	4.5	13	16	1.2
D_{3-4}: time between step 3 (prep. st.) and 4 (CF)	0	10	9	0.8
Products with measure published (N=22)				
D_T: total duration	47*	56	20	0.4
D_{CF}: duration since (first) CF meeting	21	26	17	0.7
D_{RC}: duration since RC meeting	5.5	6	2	0.3
D_3: duration preparatory study (step 3)	24	21	7	0.3
D_4: duration Consultation Forum (step 4)	4.5	11	16	1.4
D_{3-4}: time between step 3 (prep. study) and 4 (CF)	0	8	7	0.9
D_{4-8}: time between end step 4 and RC meeting	13	13	11	0.9

* Step 2 has not been included in the analysis, so total duration is 55-8=47 months

From the data we conclude that especially the duration of the Consultation Forum phase (step 4) and the time between the end of the preparatory study (step 3) and the beginning of step 4 are much longer than the norm. In the next section we present the results of the analysis of the various steps in the process to find explanations for the delays.

6.4.2. Results of analysis of various steps in the process

Step 3: Preparatory study

The aim of the preparatory study is to provide the Commission with all the information that is needed to decide whether an executive measure is justified and to prepare a draft of such measure if justified. In most cases the planning for the preparatory study is quite strict because tied to a contract with deadlines that cannot be changed without administrative burdens. The following factors therefore influence mostly the process time of other steps.

First the availability of data; as such the non or lesser availability of data can be absorbed within the preparatory study without delay. It will however heavily influence the preparation of documents for the Consultation Forum (working document) and the interservice consultation (draft executive measure). Furthermore, delays after the preparatory study can render data collected in this study obsolete and unsuitable for basing executive measures upon. An example is the study for computers where there was a delay of two years between the end of the preparatory study and the Consultation Forum meeting. Data availability is not only based on stakeholders' willingness to provide data or the existence of affordable commercial datasets but also on the availability of standard measurement methods. Commercial refrigeration products is an example where the lack of standardized measurement methods resulted in no suitable data being available for some product categories.

Second the extent of cooperation by stakeholders, especially industry. Also this factor may not only affect the process time of this step but may result in less information available to prepare documents in other steps which then leads to delays in these steps. This factor also covers withholding information that then in later steps is disclosed to challenge e.g. requirements or the scope of a measure. In general this can or should be dealt with by the consultant of the preparatory study who should be qualified on the (technical aspects of the) product.

Third, the political sensitivity of the matter. For some products, e.g. (combi-)boilers and water heaters, different (industry) groups exist that have opposite views which can result in delays because no common ground for definitions, metrics, measurement methods etc. can be found. Although regarding technical aspects the consultant should be able to deal with different views, the more political issues can raise problems.

The quality of the preparatory studies varies. The assessment of the quality by the respondents resulted in an average score of 5.4 on a scale from 1 (very bad) to 10 (excellent) with a standard deviation of 1.1. The quality partly depends on the factors indicated above but also on the quality of the consultant related to the product. A consultant with good (technical) knowledge of the product and good contacts with stakeholders will probably extract more relevant data than a consultant who merely copies the information certain manufacturers provide. Furthermore the budget for the preparatory study may not allow buying market data from commercial organizations or studying all aspects in detail.

Step 4: Consultation Forum

The link between the finalization of the preparatory study and the (preparation of the) Consultation Forum is critical because with the preparation of the Consultation Forum the Commission takes over the responsibility for the documents. The working document discussed at the Consultation Forum is a Commission document, no matter to what extent it is based on the final report of the preparatory study or even prepared by a consultant. Related to this is that the working document is a policy document whereas the study report is more of a technical document.

The results show that there is an average delay of 10 months (with a standard deviation of 9 months) between the end of the preparatory study and the start of the Consultation Forum phase. This suggests that the Commission has too little staff to handle the results from the preparatory studies, or that the (low) quality of the preparatory study or the complexity or political sensitivity of the matter requires more time for preparation.

The Consultation Forum meeting is the first formal consultation regarding the proposed executive measure. This means that several stakeholders, including Member States experts, only now ‘wake up’ and study documents for the first time.

Step 5, 6, 7: Draft executive measure, impact assessment, interservice consultation

The draft executive measure is a first consolidated working document issued by the Commission for input in the interservice consultation, i.e. the consultation of other DGs (Directorates-General) within the Commission. Consolidated means that it seeks to take into account views and comments issued in the Consultation Forum, including written comments sent to the Commission before and after the Consultation Forum meeting.

Furthermore it contains a single proposal for an executive measure, contrary to earlier working documents in the process that often contain several options for executive measures, e.g. with different level of ambition for requirements or timing. In principle the text of the draft executive measure should be such that when no comments would be issued and it would be voted and scrutinized positively the text could be adopted by the Commission and published in the Official Journal.

In this step sometimes still intensive informal bilateral discussions with stakeholders take place that can cause delays. As for the other steps there is no limit on the duration of this step. If the complexity of the matter results in complex legislative texts then this can also cause delay because the Commission Legal Service needs to be more involved.

The nature of the interservice consultation has changed recently in such way that the draft executive measure that is sent to interservice consultation is also (informally) sent to the members of the Consultation Forum. Of course this triggers comments and proposals for amendments, including those from stakeholders that see this as an extra chance to bring forward their views that were not included in the draft executive measure. This will especially happen for contentious products.

Step 8: Regulatory Committee

The Regulatory Committee only applies to ecodesign executive measures and not to energy labelling measures. However, since the Commission aims to publish both measures at the same time delays in one process also effect the other process. As with the preparation of the draft executive measure for interservice consultation, the preparation of the final draft executive measure can include intensive informal bilateral discussions with various stakeholders. If one of these stakeholders has the power to block the release of the final draft to the Committee then this can cause delays. The results show that for the published measures the average duration between the end of the Consultation Forum phase and the Regulatory Committee meeting are less than the norm in **Figure 6.1**. However, the standard deviation is almost the same as the average, indicating that for some measures this period is much larger than the norm; an example is household tumble driers where problems with the energy label also delayed ecodesign. Once the documents are sent to the Committee members and the date for the meeting is set, no delays are to be expected. There is enough (public) pressure on Member States representatives to sort out the final issues at the meeting and to vote upon the amended final draft.

Step 9, 10, 11: Scrutiny, adoption and publication

If the proposal is voted positively and no objections have been raised during the scrutiny by the European Parliament and the Council, this should be a straightforward step. Nevertheless experience shows that it sometimes can take a long time before a measure is adopted. The ecodesign executive measure for household air conditioners was voted upon positively on 31 May 2011 but was published only on 6 March 2012 due to problems with the energy labeling measure for this product and because the Commission did not want to publish the measures separately.

6.4.3. Delay factors; complexity and political sensitivity

From the foregoing results three categories of potential delay factors can be distinguished:

- Delay factors related to process organization, including capacity at the Commission and practical issues.
- Delay factors related to the quality of the preparatory study and availability of data.
- Product related delay factors: technical complexity and political sensitivity.

Finally, delays itself are causes of further delays, because (new) people need to study documents again, data has become obsolete, consensus issues are opened for discussion again, etc.

In this section we discuss these factors in more detail, focusing on the product related delay factors, showing how technical complexity and political sensitivity result in delays in the process.

Process organization, capacity and practical issues

First we note the process seems to be too elastic, i.e. deadlines – if any – can be ignored, steps can be stretched almost endlessly without consequences and ‘old’ issues can be raised at almost any point (again) in the process. This makes the process an ideal target for delaying tactics. Of course the advantages are that this offers maximum opportunities for consensus building and that serious omissions and mistakes can be corrected until the very end. Related to this is the impression that each step seems to be prepared and planned in isolation and sequential.

Second the influence of practical issues should not be underestimated, e.g. the availability of meeting rooms and translation services (both for final documents and Regulatory Committee meetings) can cause a delay of several months. Apart from careful planning and accepting meetings on unpopular days, these depend on the political priority of the issue (energy efficiency of products) compared to other issues. What can be noted though is that organizing an extra face-to-face meeting, even informally, results in a delay.

Third the capacity at the Commission (availability of staff) did not match the planning: in the beginning of the process many preparatory studies finished at about the same time and there was not enough capacity to take all products to the next steps resulting in delays. Also the absolute level of capacity was not sufficient. Since this is a general aspect, it cannot be related to specific products. For individual products we can assess the number of changes in Commission staff dealing with a product during the process. Ideally the same Commission desk officer should be involved through all the phases of the process. However for more than half of the products there has been at least one change in Commission staff during the process and for two products three staff changes were counted. Staff changes result in delays because the new desk officer needs time to become acquainted with a dossier that is full of complex technical details and with the stakeholders.

Quality of the preparatory study, availability of data

As expected the quality of the preparatory study shows no relation with the duration of the preparatory study. However the quality of the preparatory study also shows no relation with the total duration of the process. An explanation could be that the lesser quality of a preparatory study is compensated for by other analyses in the process, e.g. additional analysis for the working document or impact analysis, which require extra time by consultants but no extra process time. For several products, e.g. computers and commercial refrigeration products, the Commission used the study for the impact assessment as an extra resource to complement the preparatory study.

The availability of data, or better said the lack of up-to-date data, has been and is a problem for almost all products. The reasons are manifold: unwillingness of stakeholders to cooperate, unavailability of standard measurement methods, development of new measurement methods, new or more specific definitions of or energy efficiency metrics for products, prohibitive costs for data collection. Lack of data is especially problematic for technical complex and/or contentious products (see below) because there is no or not enough data to settle disputes. Moreover for these products the above mentioned factors itself are part of the discussions. The availability of data could not be assessed quantitatively but it is assumed that the effect on process time is incorporated in the effects of technical complexity and political sensitivity.

Technical complexity and political sensitivity

Technical complexity and political sensitivity relate to the product for which a measure is prepared. A (technical) complex product is a product with a large variation of product types, user options, features, interdependent subsystems, for which it is difficult to set an efficiency metric or for which it is not easy to measure performance. Examples of such products are especially heating products (boilers, central heating systems with hot air, water heaters). Technical complexity refers to the internal structure and performance.

Political sensitivity refers to the sensitivity of addressing the efficiency of the product, including banning certain product variants, or the measure having a significant effect on certain performance parameters or it’s influence on energy infrastructure or industry. Examples of such products are general lighting products, but also water heaters.

Technical complexity triggers the input of stakeholder and Member State experts that has to be dealt with by (experts hired by) the Commission. Furthermore, complex issues have a high chance of several experts being involved, each on a sub-aspect which requires coordination. Examples are large transformers, tapping patterns for water heaters, measurement methods for emissions of solid fuel boilers. Political sensitivity also triggers the input of extra people but now on different hierarchical levels (included in **Figure 6.2** in a simplified way). This not only introduces delays because of the time needed to pass all hierarchical levels but also because it reduces flexibility in the negotiations to arrive at a compromise. Note that in case of (large) Member States, industry organizations and NGOs an extra layer is introduced because they need to consult various ministries and/or stakeholders (Member States) or member companies or organizations (industry organizations, NGOs).

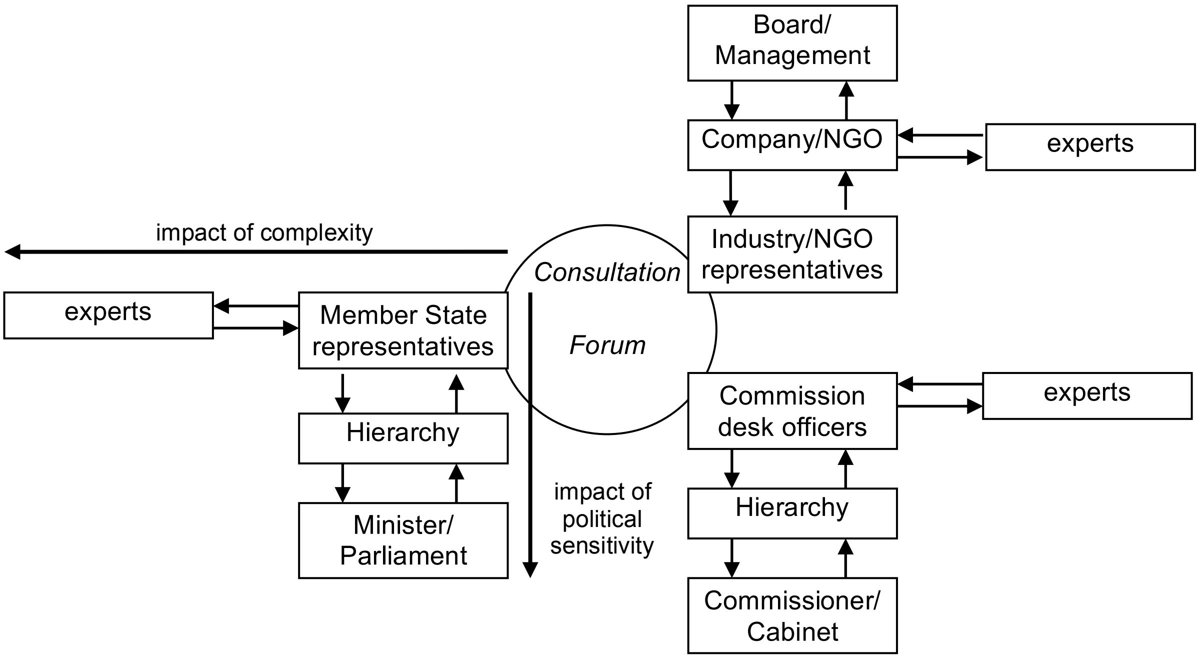

Figure 6.2 Impact of technical complexity and political sensitivity on the Consultation Forum (for simplicity the impact is indicated for Member State representatives only; impact on stakeholders and Commission is likewise)

Respondents scored technical complexity and political sensitivity on a scale from 1 (less) to 5 (more). These variables correlate (Spearman’s rho, $r_s=0.57$, $p<0.01$, two-tailed, N=41), meaning that the respondents do not score political sensitivity and technical complexity as independent. Finally, complexity and political sensitivity could also increase for products for which also an energy label measure is prepared.

6.4.4. Quantification of delay factors and impact on energy savings

In this section we try to quantify the delay factors discussed in section 6.4.3. Obviously this quantitative analysis is restricted by the small number of cases. As indicated earlier the non- availability of data and the lack of cooperation of stakeholders were also suggested to be delay factors. However these factors were considered difficult to quantify and it is assumed that they are indirectly covered by the variables quality of the preparatory study and political sensitivity.

We calculated correlations (Spearman's rho) between the delay factors. Besides the correlation between technical complexity and political sensitivity reported above, we found using data for all products (N=41) significant correlations between:

- technical complexity and the number of Consultation Forum meetings (r_s=0.39, $p<0.05$);
- quality of the preparatory study and the number of Consultation Forum meetings (r_s=-0.35, $p<0.05$);
- political sensitivity and the number of changes in Commission staff (r_s=0.35, $p<0.05$);
- the number of changes in Commission staff and the number of Consultation Forum meetings (r_s=0.41, $p<0.05$).

When looking at products for which a measure has been published (N=22), only the last correlation is significant (r_s=0.66, $p<0.01$).

The first two correlations are more or less self-explanatory. More complex products need more discussion with stakeholders and therefore need a larger number of Consultation Forum meetings. On the other hand if the quality of the preparatory study increases less Consultation Forum meetings with stakeholders are needed. Political sensitivity might trigger changes in Commission staff because a new and/or more experienced desk officer is needed to deal with a product that is more sensitive, but it also might simply be the case that the process for a more sensitive product takes longer and therefore the chance of a change in Commission staff is higher. The latter explanation might also be applicable to the correlation between the number of changes in Commission staff and the number of Consultation Forum meetings. In that case this correlation is spurious because both variables relate to the duration of the process.

Taking all products into account a Mann-Whitney U test indicated that political sensitivity was significantly lower for products without an energy label measure (Mean Rank=18.07, n=27) than for products with an energy label measure (Mean Rank=26.64, n=14), U=110.00, z=-2.18, p=0.030 (two-tailed). Also changes in Commission staff were significantly lower for products without an energy label measure (Mean Rank=16.98, n=27) than for products with an energy label measure (Mean Rank=28.75, n=14), U=80.50, z=-3.27, p=0.002 (two-tailed).

Restricting the analysis to products for which a measure has been published a Mann-Whitney U test confirmed the difference in changes in Commission staff but not the differences in political sensitivity. Furthermore the number of Consultation Forum meetings was significantly lower for products without an energy label measure (Mean Rank=8.83, n=12) than for products with an energy label measure (Mean Rank=14.70, n=10), U=28.00, z=-2.57, p=0.036 (two-tailed). The latter relation is plausible because for product for which also an energy labeling measure is prepared there are more issues to be discussed.

We further looked into the relation between the delay factors and duration of the preparatory study (D_3), the duration of the Consultation Forum phase (D_4) and the duration between the end of the preparatory study and the start of the Consultation Forum phase ($D_{3\text{-}4}$). A Kruskal-Wallis ANOVA indicated that there were significant differences between:

- D_4 for products with 0, 1, 2 and 3 changes of Commission staff, H (corrected for ties)=11.300, df=3, N=33, p=0.010, Cohen's f=0.739. Follow-up analysis using a Mann-Whitney U test, confirmed that the difference in D_4 between products without changes in Commission staff (Mean Rank=12.00, n=13) and products with 1 or more changes in Commission staff (Mean Rank=20.25, n=20) was significant, U=65.00, z=-2.62, p=0.016 (two-tailed);
- D_4 for products with 1 (Mean Rank=10.16, n=19), 2 (Mean Rank=24.20, n=10) and 3 (Mean Rank=31.50, n=4) Consultation Forum meetings, H (corrected for ties)=28.763, df=2, N=33, p<0.001, Cohen's f=2.983. Follow-up analysis using a Mann-Whitney U test, using a Bonferroni corrected alpha, confirmed that the individual differences were significant;
- $D_{3\text{-}4}$ for products with a preparatory study with 'low' (score≤4.7), 'average' (4.7<score≤5.9) and 'high' (score>5.9) quality, H (corrected for ties)=8.451, df=2,

N=29, p=0.015, Cohen's f=0.658. Follow-up analysis using a Mann-Whitney U test confirmed that the difference between $D_{3\text{-}4}$ for products with a 'low' quality preparatory study (Mean Rank=16.72, n=9) and for products with a 'high' quality preparatory study (Mean Rank=8.96, n=14) was significant, U=20.50, z=-2.61, p=0.005 (two-tailed).

Restricting the analysis to products for which a measure has been published (N=22), we looked in to the relation between the delay factors and D_3, D_4, $D_{3\text{-}4}$, the total duration (D_T) and the duration since the (first) Consultation Forum meeting (D_{CF}). A Kruskal-Wallis ANOVA confirmed the significant differences that were reported above for this restricted group. Furthermore significant differences were indicated between:

- D_T for products with 0, 1, 2 and 3 changes of Commission staff, H (corrected for ties)=8.079, df=3, N=22, p=0.044, Cohen's f=0.791. Follow-up analysis using a Mann-Whitney U test confirmed that the difference in D_T between products without changes in Commission staff (Mean Rank=7.83, n=9) and products with 1 or more changes in Commission staff (Mean Rank=14.04, n=13) was significant, U=25.50, z=-2.21, p=0.025 (two-tailed);
- D_{CF} for products with 0, 1, 2 and 3 changes of Commission staff, H (corrected for ties)=10.747, df=3, N=22, p=0.013, Cohen's f=1.024. Follow-up analysis using a Mann-Whitney U test confirmed that the difference in D_{CF} between products without changes in Commission staff (Mean Rank=7.22, n=9) and products with 1 or more changes in Commission staff (Mean Rank=14.46, n=13) were significant, U=20.00, z=-2.58, p=0.009 (two-tailed);

A Mann-Whitney U test indicated that $D_{3\text{-}4}$ for products without an energy label measure (Mean Rank=7.30, n=10) was significantly lower than for products with an energy label measure (Mean Rank=13.70, n=10), U=18.00, z=-2.44, p=0.015 (two-tailed). Also D_T for products without an energy label measure (Mean Rank=8.50, n=12) was significantly lower than for products with an energy label measure (Mean Rank=15.10, n=10), U=24.00, z=-2.39, p=0.017 (two-tailed).

Summarizing the results we note that changes in Commission staff influence the duration of the Consultation Forum phase (D_4), the duration since the first Consultation Forum meeting (D_{CF}) and the total duration of the process (D_T). The differences in average duration between products with no change and products with at least one change give an indication of the effect: for D_4 the difference is 15 months, for D_{CF} the difference is 13 months and for D_T the difference is 24 months.

Although the quality of the preparatory study does not relate to D_T, the duration between the end of the preparatory study and the start of the Consultation Forum phase ($D_{3\text{-}4}$) does: if the quality is ‘low’ this duration is on average 17 months, if the quality is ‘high’ the duration is on average 6 months. The time to repair a ‘low’ quality preparatory study is about one year.

Furthermore if the product also has an energy labeling measure, $D_{3\text{-}4}$ is on average 5 months longer than for products without an energy label. Products with an energy label have an average D_T of 66 months, products without an energy label 47 months. This difference can not only be due to the procedural differences: according to **Figure 6.1** the difference in procedure is 4 months because step 8 (the Regulatory Committee) is not part of the energy labeling procedure.

It is not surprising that the number of Consultation Forum meetings influences the duration of the Consultation Forum phase. However the size of the influence is considerable: the difference in average duration of products with one and two Consultation Forum meetings is 14 months and the difference between products with two and three Consultation Forum meetings is 32 months.

The impact of the delays on energy savings is considerable. The example in the introduction estimated the cumulative lost savings of the delay in the measures for boilers and water heaters to be more than 7000 PJ which is about the gross inland energy consumption of Italy in 2011 (European Union Commission 2013, p. 186). The total savings of electrical products for which a measure is published is estimated at 485 TWh per year in 2020 according to the impact assessments for the products. The lost savings are estimated by multiplying the delay (actual total duration minus total duration as indicated in **Figure 6.1**) expressed in years with the estimated savings per year, resulting in lost savings of 263 TWh, which is about the gross electricity generation of Sweden and the Netherlands in 2011 (European Commission 2013, p. 81) and is equivalent with 98 Mt CO_2 emissions.

6.4.5. In and out of comitology

For 14 product groups both ecodesign and energy labelling measures have been adopted (10 products) or are being developed (4 products). As indicated in **Figure 6.1** the process for both measures is the same until step 8: ecodesign measures are voted upon by the Ecodesign Regulatory Committee whereas energy labelling measures are adopted by the Commission. In this section we identify issues related to the different procedures (in and out of comitology) for ecodesign and energy labeling measures and the consequences for the duration of the process.

The first issue is that different measures exist although they target the same product. The alignment of both measures is an important aspect: scope, definitions, exemptions, metrics and measurement methods are preferably the same in both measures in order to save costs for industry and governments. Differences in measurement methods could mean that the same product has to be tested twice, once for compliance with each measure. Another aspect is alignment of the minimum efficiency requirements with the energy label scale. It is easier for e.g. enforcement of the measures if the minimum efficiency requirements coincide with an energy label class, e.g. C, because in that case it is clear that no products with class D (or lower) are allowed on the market.

The second issue is that the procedure for adopting energy labelling measures is less transparent regarding finalization of the text compared to the comitology procedure for ecodesign. For ecodesign the final text is voted upon, after begin discussed and amended, in the Regulatory Committee which means that apart from the Commission at least Member State experts have insight in how the final text is established, whereas for energy labelling measures the text is finalized by the Commission. One could say that this places Member States on equal footing with the other stakeholders that are not part of the Regulatory Committee. However the experts in the Regulatory Committee being Member States representatives are supposed to take into account in their position and negotiations the opinions of the (national) stakeholders. In any case without comitology the focal point in time for finalizing the text of measures is lost which can result in delays.

An example of this is the energy label for boilers where Member State experts arrived at a compromise at a Consultation Forum meeting on 29 June 2012 but the Commission continued (bilateral) discussions with industry and other stakeholders resulting in the adoption of the energy label being delayed until 18 February 2013. Several other related issues arise; removing comitology mobilizes fewer resources from Member States in the final stage and Member States have less influence on the final text. Although one of the criticisms on comitology is that Member States have a large say in finalization of measures, the other side of the coin is that technical and practical expertise is needed to develop proper ecodesign and energy labelling measures and that Member States are responsible for verification and enforcement of the measures. With the current Commission staff and budget the Commission is not able to secure all the technical expertise needed. The recently introduced Member State Expert Consultation Forum in which the final text of the energy label measured is discussed does not fill this gap completely because it has only an informal advisory status. Removing comitology also decreases the shared responsibility for executive measures which is important certainly if the measure is political sensitive, e.g. the phasing-out of incandescents.

Finally, the non-comitology procedure provides more opportunity for single interest lobbying, e.g. an industry organization that wants to have a specific part of a proposal changed. Whereas in case of comitology this organization has to convince at least a qualified majority of Member States in case of non-comitology only the DG of the Commission that is responsible for the dossier has to be approached. This provides especially advantages for stakeholders with good access to the Commissioner; examples are the energy label measures for televisions and boilers.

Because the process of ecodesign and energy labeling measures is tightly coupled and the Commission intends for good reasons to publish both measures at the same date in the Official Journal the quantitative results can not be used to judge whether removing comitology results in a faster process. As indicated above, theoretically measures without comitology could be published 4 months earlier; on a total duration of 55 months this is an improvement of 7 %. In practice this would be less because **Figure 6.1** does not include the Member State Expert Consultation Forum.

Concluding, removing comitology from the procedure goes from bad to worse, i.e. it does not improve the disadvantages of comitology, e.g. intransparency and the democratic deficit but increases these by making the procedure more fuzzy and prone to single interest lobbying. Furthermore, removing comitology does not seem to speed up the procedure but on the contrary seems to introduce further possibilities for delays.

6.5. International comparison

In this section we compare the ecodesign process with the process to establish Top Runner standards in Japan and the DOE (Department of Energy) rulemaking process for setting appliance standards in the USA. The Top Runner process can be summarized as follows (METI 2010, p. 10-12); see also chapter 3 and **Figure 6.3**. The Energy Efficiency Standards Subcommittee, a subcommittee of the Advisory Committee for Natural Resources and Energy, evaluates proposals for candidate products for the Top Runner programme. If a Top Runner standard for a certain product is to be set, an Evaluation Standard Subcommittee is established. If necessary, to prepare for the Top Runner standard and measurement method studies are conducted and the results discussed in working groups. In these working groups industry experts, academia and consumer groups participate. After the working groups have formulated a recommendation, the Evaluation Standards Subcommittee prepares a first draft of the Top Runner standard. This draft is published in an interim report for public comment. The comments are processed and a final report with a final draft standard is published. Also the final draft is notified to the WTO. The Advisory Committee for Natural Resources and Energy does the authorization of the new standard. According to METI (2010, p. 12) this process (from step 2) takes 24 to 30 months.

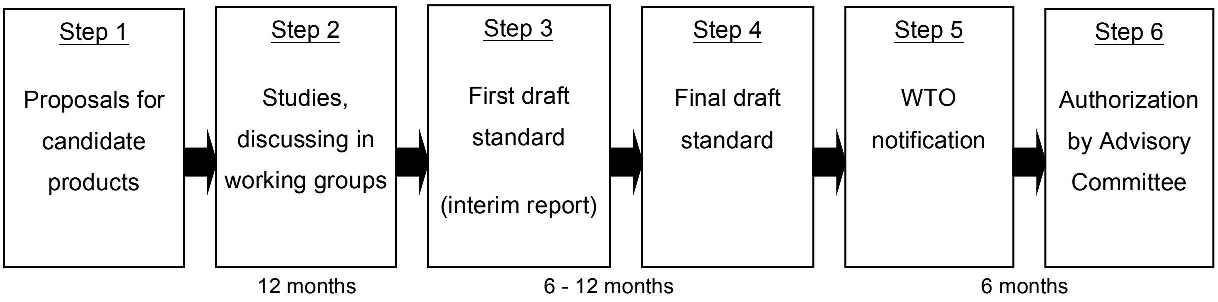

Figure 6.3 Top Runner standard setting process

The DOE rulemaking process is determined by the Process Rule of 1996 and can be summarized as follows (US DOE 2006, p. 18-31; especially figure 1 on p. 20); see **Figure 6.4** for a simplified representation. If there is not already a statutory or legislative mandate for DOE to set a standard for a certain product, the first step is a Determination Analysis to determine if a mandatory standard is technologically feasible and economically justified. To that extent a Notice of Determination for the product is published in the Federal Register and the public (i.e. stakeholders) are invited to provide input to DOE. Once DOE determines that a rulemaking will be undertaken, DOE prepares a Framework Document describing DOE's plans and posts a Notice of Availability, including the Framework and other relevant documents, on its website. Furthermore DOE asks again for comments and organizes a public meeting. In the third step an engineering, market and cost-benefit analysis is conducted. The results of this analysis are published in an Advance Notice of Proposed Rulemaking (ANOPR), including a Technical Support Document, in the Federal Register. The publication of the ANOPR is followed by a comment period and another public meeting. In the fourth step DOE revises the comments and addresses them in a Notice of Proposed Rulemaking (NOPR) which is published in the Federal Register. In the fifth and final step DOE considers again comments and takes them into account when publishing the Final Rule (i.e. the standard) in the Federal Register.

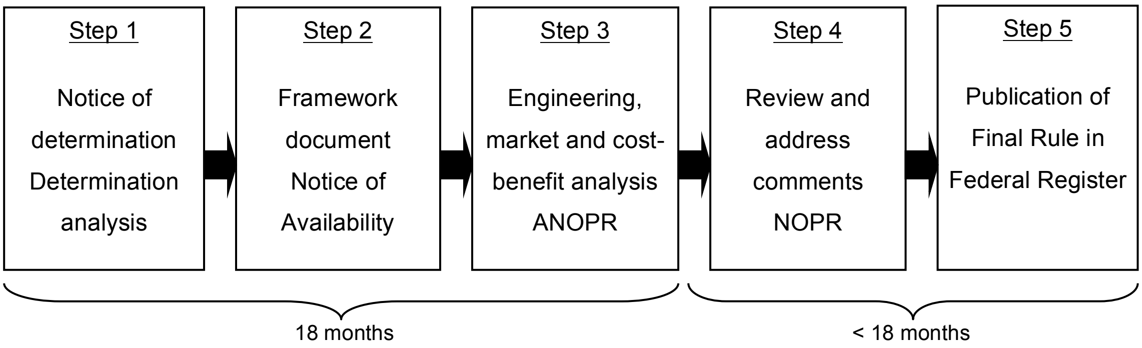

Figure 6.4 DOE rulemaking process

The total process should not take longer than 3 years and the period from the publication of the ANOPR until the publication of the Final Rule should be less than 18 months. However, in 2005 it became clear that DOE failed to meet the deadlines under the Energy Policy Act of 2005 to deliver new or amended appliance standards. Moreover the time between ANOPR and NOPR had increased from 12 months to between 23 and 26 months and the time between NOPR and final rule increased from between 6 and 8 months to 12 months. An analysis of the causes for the missed deadlines and the delays revealed the following (US DOE 2006, p. 32-41):

- The priority setting process resulted in stopping the work on products that were not the highest priority.
- The open nature of the process introduced delays because the policy of sharing drafts and accepting stakeholder comments on an on-going basis resulted in a fragmented and inefficient process.
- Many aspects of the rule making process that made it more robust also made it more voluminous, complex and time-consuming.
- The external (to DOE) reviews added up to 1 year to the process.
- The sequential process made it impossible to recover delays.

In this analysis we recognize several of the delay factors identified for the ecodesign process: the external reviews (in the EU: impact assessment and ISC), the sequential and open nature of the process.

Improvements to clear the backlog and shorten the actual process time to achieve the 3 year target for the rule making process included (US DOE 2006, p. 42-52):

- Improved process management of parallel rule making, including a cross-cutting review team.
- Reintroduce bundled product rule makings, e.g. for white goods.
- Greater discipline in keeping deadlines for comments, including standardizing document formats.
- Streamline the analysis.
- Hiring more staff.

Both the DOE analysis and the suggestions in this chapter indicate that in general a 3 year schedule from the start of the study phase to the final publication of the measure seems a reasonable time span. A shorter duration would leave too little time for the study (data collection, technical-economical analysis) and negotiation. A longer duration runs the risk of creating its own delays, e.g. due to increased risk of staff changes. As in the DOE process in the first half of the process the emphasis should be on technical-economical analysis, whereas in the second half the emphasis could be on negotiation between government and stakeholders. However, as we have seen above the assessment of complexity and contentiousness could fine tune the balance between technical preparation and negotiation. In order for the Commission to meet a 3 year schedule the internal process organization, including capacity and priority management, should be improved and – certainly for revisions of existing measures – the time for the preparatory study could be reduced to 18 or 12 months.

6.6. **Summary, conclusion and recommendations**

Improving (the process of) EU law making has been on the agenda since a long time. In this chapter we looked into one aspect of lower level law making, the duration and especially the delays in the process. This is an important aspect of effectiveness, certainly for product efficiency where delayed measures result in less energy savings. Since the adoption of the first Ecodesign directive (2005/32/EC) 22 regulations have been published in the Official Journal. We found that since 2010 none of the published measures have met the planning as indicated by the Commission which has a total duration of 47 months. The average duration is 56 months, for measures published since 2010 this is 71 months with a minimum of 51 months and a maximum of 91 months. The lost savings due to delays are estimated at more than 7000 PJ for boilers and water heaters and 263 TWh for other products. Especially the duration between the end of the preparatory study and the start of the Consultation Forum phase, and the duration of the Consultation Forum phase itself are much longer than the norm, the duration indicated in the planning of the Commission.

From the analysis of the process the following reasons for delays (delay factors) could be identified:

- Process organization and capacity: the capacity at the Commission did not match the workload. To quantify the impact of process organization the number of staff changes at the Commission for a product was used as a proxy: having at least one staff change adds on average 15 months to the Consultation Forum phase.

- Quality of the preparatory study and available data: the quality of the preparatory study relates to the duration between the end of the preparatory study and the start of the Consultation Forum phase; for products with a low quality preparatory study this duration is longer. The availability of data has been and is a problem for almost all products. It could not be assessed quantitatively, but it is assumed that the effect on process time is incorporated in the effects of technical complexity and political sensitivity.
- Technical complexity and political sensitivity: whereas the foregoing delay factors are related to (specific parts of) the process, technical complexity and political sensitivity relate to the product for which a measure is prepared. According to the scores of respondents both variables are related: the higher the score for technical complexity, the higher the score for political sensitivity of the product. Technical complexity relates to the number of Consultation Forum meetings: the larger the technical complexity, the higher the number of meetings.

For 14 products both an ecodesign measure and an energy label measure have been or are being prepared in parallel. This allowed for a qualitative comparison of the final stages of the process 'in and out' of comitology: in for the ecodesign measure, out for the energy label measure for the product. Comitology in general has been criticized for being obscure and lacking accountability, however the results in this chapter suggest that moving out of comitology may go from bad to worse. Both ecodesign and energy label measures are scrutinized by the EP and the Council; however this concerns the final text that can not be amended. Comitology for ecodesign in the form of the Regulatory Committee forces at least Member States to take a formal position regarding the proposal to be voted upon including possible amendments. In any case for the Member States it is clear how the final text was established because they were present at the meeting. The issue of accountability and transparency then moves to the Member State level. For the adoption of highly complex and technically detailed legislation like ecodesign and energy label measures comitology turns out to have at least three other advantages: securing Member State expertise, securing Member State support for the legislation and being less vulnerable to single interest lobby. The 4 months gained in theory by removing comitology will be in practice used by the Member States Expert

Consultation Forum that discusses the final text for an energy label measure but has only an advisory status. Comitology with scrutiny may be the right procedure for complex and technically detailed executive measures. To increase openness to the legislator the Regulatory Committee meetings could have EP members as observers.

The results suggest that the process can be improved and the delays can be reduced. Obviously but in time of shrinking budgets politically less acceptable, increasing the capacity at the Commission and the budget for preparatory studies can reduce delays. Increased budget could secure sufficient data and increased capacity allows the Commission to better manage the larger number of measures and their reviews in parallel.

Furthermore the process can be improved by taking explicitly technical complexity and political sensitivity into account in the planning. Products that have a lower than average technical complexity and political sensitivity could have a shorter or more strict process whereas especially for products that are both technical complex and contentious the Consultation Forum phase could be more elaborate with e.g. two Consultation Forum meetings planned instead of one. In general this makes the process more predictable which is better for Member States, industry and other stakeholders. The upcoming review of the energy labeling and ecodesign directives provides an opportunity to structure and standardize the process more clearly.

Taking a broader view the question arises whether anyhow the duration of 47 months as indicated by the Commission is a suitable duration for lower level law making in the field of product efficiency policy. Looking at similar processes in other parts of the world (US, Japan) 3 years seems to be a suitable time: 1 year for preparation, 1 year for consultation (2 years for complex/contentious products) and 1 year for adoption and publication. Assuming that a 3 year process would allow for setting requirements with the same stringency the extra savings for the 20 measures (boilers and water heaters excluded) that have been published in 2010-2013 would be 333 TWh. A shorter process would also reduce the chance of changes in Commission staff.

Annex: overview of products for which an ecodesign and/or energy labelling measure has been published or is being prepared - Status: 1 October 2013

Product group	**measure**[a]	**QPS**[b]	**TC**[c]	**PS**[d]	**Duration (months)**						
					D_T	D_{CF}	D_{RC}	D_3	D_4	D_{3-4}	D_{4-8}
Boilers and combi-boilers (gas/oil/electric)	E/L	6.0	4.8	4.8	91	67	6	19	55	4	9
Water heaters (gas/oil/electric)	E/L	6.0	4.2	4.4	91	67	6	19	55	4	9
Personal Computers (desktops & laptops)	E	3.9	3.1	3.1	88	44	4	19	3	24	40
Computer monitors	e/l[f]	4.4	2.5	2.4	91	47		19	39	24	
Consumer electronics: televisions	E/L	4.7	2.4	2.9	41	9	4	18	3	13	5
Standby and off-mode losses	E	7.0	2.7	2.7	34	14	5	20	3		9
External power supplies	E	6.2	1.5	1.6	38	14	6	11	3	12	8
Office lighting	E	5.5	3.0	2.7	37	15	6	14	3	7	9
(Public) street lighting	E	5.8	3.2	3.1	37	21	6	11	3	4	15
Residential room conditioning appliances and fans	E/L	6.2	3.5	2.9	73	33	10	26	13	13	13
Electric motors 0,75-375 kW	E	7.0	2.8	2.9	41	14	4	26	3		10
Circulators in buildings	E	7.1	2.2	2.2	41	14	4	26	3		10
Electric pumps	E	6.9	2.6	2.0	76	49	6	26	3		43
Industrial fans	E	6.0	3.6	2.1	61	34	9	26	25		3
Professional refrigerators and freezers	e	3.5	3.4	2.3	91	41		22	44	27	
Domestic refrigerators and freezers	E/L	6.4	2.2	2.6	41	7	4	22	3	11	3
Domestic washing machines	E/L	6.4	2.2	2.4	57	23	6	22	18	11	2
Domestic dishwashers	E/L	6.3	2.0	2.3	57	23	6	22	18	11	2
Solid Fuel Small Combustion Installations	e/l	4.6	3.7	3.2	72	14		28	3	29	
Household tumble driers	E/L	5.5	2.0	2.1	80	28	5	37	3	14	23
Vacuum cleaners	E/L	4.1	2.3	1.9	66	37	5	13	18	15	17
Domestic lighting products (general lighting)	E/L[e]	6.2	3.1	4.8	37	12	3	32	3		9
Domestic lighting products (direct lighting, LED)	E/L[e]	6.1	3.6	4.4	60	17	5	23	3	19	12
Simple set top boxes	E	6.8	1.6	1.5	26	12	5	12	3	1	7
Local room heating products	e/l	5.4	3.2	3.4	51	12		36	3	2	
Central heating products using hot air	e	5.0	3.8	2.7	51	10		37	13		
Domestic ovens, hobs and grills	e/l	4.6	2.5	2.5	51	17		26	6	7	
Commercial ovens, hobs and grills	e	4.3	2.7	2.0	51	17		26	6	7	
Professional washers, dryers and dishwashers	e	4.3	2.7	1.8	51			23			
Non-tertiary coffee machines	e	4.1	1.7	2.1	51	21		22	3	7	
Networked standby losses of EuPs	E	6.7	3.5	2.7	50	23	5	24	3	2	18
Domestic uninterruptible power supplies (UPS)	e	[g]	2.0	1.5	20						
Waste water pumps	e	4.0	3.5	1.6	21						
Clean water pumps	e	4.5	2.9	1.7	21						
Electrical motors (other than induction)	e	5.0	3.3	2.3	18						
Compressors	e	[g]	3.5	1.8	18						
Commercial refrigerating and freezing equipment	e	4.2	3.6	2.4	57	41		29	44		
Transformers	e	4.8	3.7	3.4	56	17		24	20	14	
Sound and imaging equipment	e	5.6	2.5	2.0	56			23	13	22	
Industrial and laboratory furnaces and ovens	e	4.0	3.9	2.9	44						
Air-conditioning and ventilation systems	e/l	6.2	3.9	2.8	44						

[a] E/L: ecodesign/energy label measure published in the Official Journal, e/l: ecodesign/energy label measure in preparation; [b] QPS: quality of preparatory study (from 1 (very bad) to 10 (excellent)); [c] TC: technical complexity (from 1 (less) to 5 (more)); [d] PS: political sensitivity (from 1 (less) to 5 (more)); [e] published in the same energy label measure; [f] energy label to be merged with energy label for televisions; [g] non of the respondents had experience with these preparatory studies.

7.

A modular functional approach to product efficiency standards[74]

Abstract

Rapid innovation in product design challenges the current methodology for setting standards and labels, especially for electronics, software and networking. Major problems include defining the product, measuring its energy consumption, and choosing the appropriate metric and level for the standard. Most governments have tried to solve these problems by defining ever more specific product subcategories, along with their corresponding test methods and metrics. An alternative, the modular functional approach, would treat each product as something that delivers a basket of functions. Then separate standards would be constructed for the individual functions that can be defined, tested, and evaluated. Functional modules for networked standby – based upon the EU regulation – and for displays are presented. These show that the modular functional approach can be useful to extend the range of MEPS by providing for a horizontal approach across products for certain functions, e.g. connectivity and display of information. However, without at least the development of a metric and test procedure for the processing function, the modular functional approach cannot be a full replacement of the current methodology for electronic products. Recommendations are given to further develop the approach and from which also the current methodology would benefit.

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[74] Adapted from the paper published in the 2014 ACEEE Summer Study Proceedings under the title "Assembling Appliance Standards From a Basket of Functions" (Siderius and Meier 2014).

7.1. **Introduction**

The classic, traditional approach for adopting product efficiency measures such as minimum efficiency performance standards (MEPS) and energy labels for individual products goes along the lines of Turiel et al. (1997); see also **Figure 7.1**. After the general product selection, it is defined which specific products are in the scope of the measure, metrics that reflect the aspects to be regulated are defined, including test procedures to assess these metrics, and finally MEPS and/or labelling classes are established. Monitoring, verification and enforcement, and evaluation are essential to ensure that the expected energy savings are realized and to learn for subsequent policy cycles.

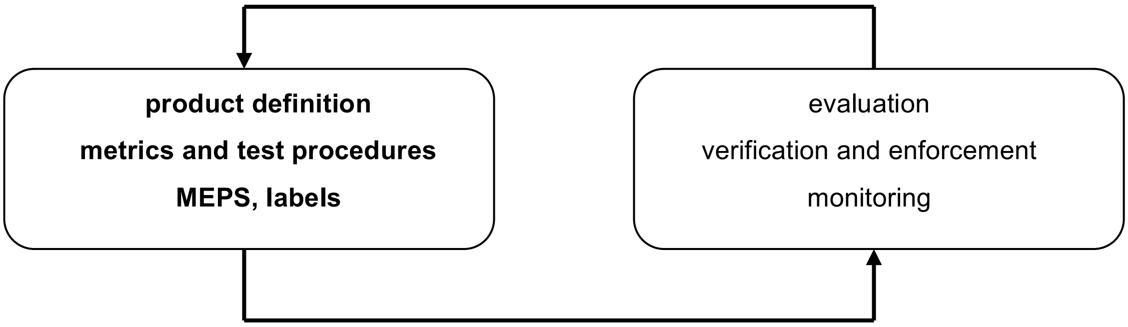

Figure 7.1 Process for adopting and evaluating product efficiency measures

Figure 7.1 suggests that the process is dynamic, i.e. MEPS and labels are regularly revised. The practical set-up of the approach, including organizing stakeholder involvement, has been documented in Wiel and McMahon (2005) and in Ellis et al. (2010) for the right hand side of **Figure 7.1**. This chapter focuses on MEPS and on the left hand side of **Figure 7.1** (steps in bold).

Evaluation studies (IEA (2000), Lowenberger et al. (2012)) show that MEPS and energy labels are successful policies. Because of the success of MEPS and labels, governments are regulating more products, e.g. in 2009 the European Union enlarged the scope of the ecodesign directive from energy-using products to energy-related products (see section 1.2.3). Furthermore, because of the success of MEPS and labels, the energy consumption of the ‘classic’ MEPS products - large household appliances - is decreasing. The impact of electronic products, i.e. consumer electronics (CE) and information and communication technology (ICT) products, on household and commercial electricity consumption is significant and expected to grow (Ellis 2009). In the EU, 17 % of residential electricity consumption is used by these electronic products (Bertoldi et al. 2012, p. 35).

As we show in the next section, product development and especially development in ICT, including software, have posed challenges to the classic approach of setting MEPS. The goal of this chapter is to explore an alternative approach to setting MEPS in response to one of these challenges, the multifunctionality of products. More specifically, we investigate whether a function-oriented approach to setting standards instead of a product-oriented approach is possible and what the pros and cons are. This chapter is organized as follows. First we explore and analyse in more detail problems with the classic approach. Then we propose an alternative based on a modular functional approach, i.e. an approach that treats a product as a basket of functions that can be evaluated individually, to address the challenge of multifunctionality of products. We apply a functional approach to video displays and network equipment. Finally we assess the pros and cons of the approach, draw conclusions and provide recommendations.

7.2. Challenges for the classic approach

7.2.1. Introduction; energy services and functions of products

A product uses, amongst others, energy to produce energy services. Generating heat, cold, light, mechanical action and processing are basic energy services. Based on Lancaster (1966), we assume that not the energy services themselves but the functions they deliver are of interest for the end-user (see **Figure 7.2**); examples of such functions are a clean wash, a comfortable environment, food preservation and entertainment.

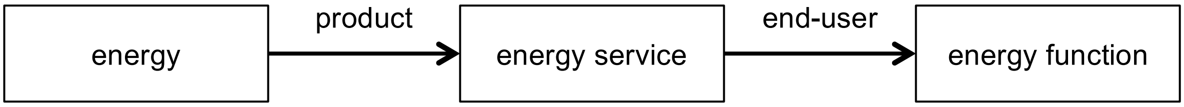

Figure 7.2 From energy to energy function

The distinction between energy services and functions is important. Functions, as defined here, require involvement of the user and energy services do not. A particular function might be realized in another way without using an energy-using product. Clothes can be dried with an electric dryer but also by using a clothesline. The product might produce the energy service while there is no end-user to enjoy the function delivered by the service, meaning that the function of the service is zero.

Basic energy services have existed since the first energy using products were invented: water heaters, refrigerators, lamps, vacuum cleaners and radios. Two developments dramatically changed energy-using products. First, electronics, such as transistors and integrated circuits developed in the 1950s and 1960s, enabled smaller and more reliable products and better control. But especially the development of microprocessors and software from the 1970s and 1980s onwards provided flexibility and resulted in new products like personal computers and tablets where the software determines the function. Nowadays there is hardly any product in the home or office that is not equipped with a microprocessor and software. Second, in the last decade, connectivity has become an important function of ever more products. Although home networks existed previously, based on the X10 protocol developed in the 1970s, only with the arrival of the (wireless) Internet, including the Internet protocol (IP), connectivity became a ‘practical’ and widespread feature. Products become dependent on other products and functionality can easily change through software updates over the Internet.

The combination of software playing a major role in the function of the product and dependence on connectivity for the functionality of the product creates ‘virtual’ products. Virtual means that the function the product provides is produced by energy services outside the product. The Internet-connected thermostat is an example of a virtual product. As a contrast, classical products can function without being connected to a network and the software is not definitive for the function of the product.

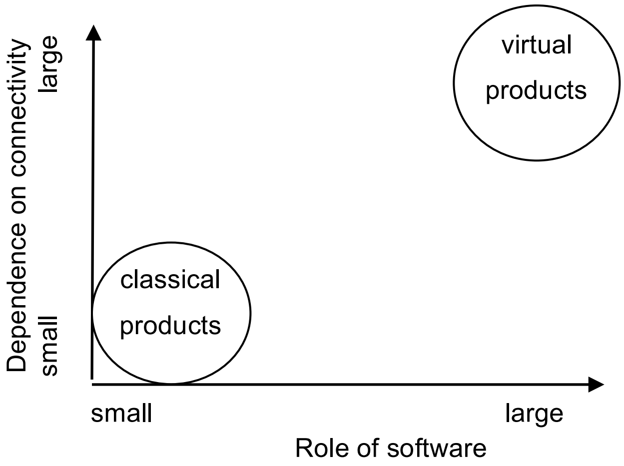

Figure 7.3 Product topology

Figure 7.3 depicts this topology; the trends described in this section suggest that products will migrate towards the upper right hand part of the graph. The next section looks into the challenges these developments pose on the classical approach of setting MEPS.

7.2.2. Challenges for the classic approach

Product development in general, but especially the increasing role of software and importance of connectivity result in products that have multiple functions, are always connected to a network and can change or adapt functionality. In this section we analyse the consequences of these developments for the classical approach of setting MEPS.

The classical approach starts with the ***definition of the product***. An important function of product definition in policy measures is to define the scope of the measure, i.e. the product definition determines which products are subject to the measure and which products are not. In the past the definition of the product was identical to the main function of the product, e.g. a refrigerator provides one or more conditioned volumes at certain temperatures, a television receives broadcast signals and provides picture and sound. A consequence of multiple functions is that if the scope of a measure is defined in a restrictive way, it is easy for products to be out of scope by adding a function that is not in the definition. An example is the differentiation between televisions and monitors based on the presence of a tuner to receive broadcast signals. Nowadays it is easy and relatively cheap to add a tuner to a monitor so that it becomes a television. Another example is the home gateway. If this product is defined as a product offering Internet connection, WLAN and telephone and router services, then a gateway with network attached storage (NAS) will be out of scope. The solution to these problems is to use more generic product definitions where everything that is not explicitly excluded is included. However this will move the problems to the next steps of the process, defining metrics and test methods and setting MEPS. In the example of the gateway, this would require defining metrics and MEPS for products with and without NAS.

Changing functionality – after the product has been placed on the market – is not a problem for the product definition, because the function and the definition of the product is in principle clear when testing the product (before placing it on the market). The set-top box is an example where software updates for deployed products are carried out to increase functionality; these updates can also impact power consumption. Also for more traditional household appliances like washing machines, firmware[75] updates are possible, although a technician at the machine mostly does this. MEPS loose credibility and effectiveness when changing functionality results in higher energy consumption, although the functionality might be improved.

MEPS and labels are based on ***metrics*** that operationalize the (main) functions of the product related to the energy or power consumption of the product. These metrics are assessed by appropriate ***test procedures***. Test procedures prescribe which measurements are needed and how these are to be performed to arrive at results. Then the results are used to calculate the metrics for which the MEPS levels are set. In most cases standards contain these test procedures, e.g. IEC 62552 for testing refrigerators. Standards prescribe in detail amongst others the input to the product, such as the load of dishwashers, the broadcast stream for a television or the power supply; the measurement conditions, such as temperature, humidity and position of the product; the measurement equipment and the actual measurements. The *ideal* test procedure should be (Siderius 1991):

- Repeatable: give the same results when the same product is retested under the same conditions, e.g. in the same laboratory by the same staff;
- Reproducible: give the same results when the same product is retested under somewhat different conditions, e.g. in another laboratory;
- Valid: give results that correspond to the results obtained in practice (at the end-users);
- Affordable: provide results at low costs.

In practice, these criteria are incompatible, especially when the use and usage conditions at the end-users vary.

Multiple functions can be dealt with in several ways. Using several metrics increases the complexity of the test procedure and the costs, certainly if a separate test has to be

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[75] Firmware is the combination of persistent memory and program code and data stored in it (IEEE 2007, p. 438).

performed for each metric. We describe two alternatives that use a single metric. The first is the use of an energy efficiency index: the power or energy consumption measured is normalized by a formula taking into account different functions. The EU ecodesign regulation for cold appliances uses this approach which takes into account not only the volume and temperature of the compartments but also the climate class, the frost free function and whether the appliance is built-in[76]. The second approach is using allowances for additional functions, which does not involve the metric but the setting of the MEPS level. In this case the MEPS level is set based on the functions of the product. An example of this approach is the ENERGY STAR specification for computers where the maximum total energy consumption (TEC) requirement is composed of a base allowance plus functional adder allowances for e.g. graphics, memory and storage. Finally, with multiple functions the chance increases that not all functions can be taken into account and therefore a choice must be made which functions to include and which not.

Changing functionality, especially awareness of the test situation, is an increasing risk for test procedures. The product recognizes that it is being tested and adapts its functionality and performance to artificially improve the efficiency. Especially when performance is not tested at the same time, energy consumption can easily be decreased by lowering the performance. Examples are refrigerators that recognize being tested and then switch off features and thus use less energy for the cycle than they will in practice (Saito 2012). Since the performance is not measured, the impact on performance is not clear, but the energy consumption in the test will not occur in practice. Recognition of test conditions is a consequence of the very detailed prescription of test procedures in standards, e.g. regarding the timing of actions. This level of detail is driven by the aim to increase the repeatability and reproducibility of test methods. Solutions are to include a degree of randomness, or to measure the performance or critical parameters. However these solutions increase the complexity and costs of the tests whereas including randomness will decrease the repeatability and reproducibility.

The last step in the process of setting MEPS is to decide upon the actual ***MEPS levels***. Guidance for setting MEPS levels is provided by e.g. life cycle costs calculations, price developments of products or technical analysis; see e.g. chapters 4 and 5. If

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[76] OJ L 191, 23.7.2009, p. 61-66 (Annex IV).

multifunctionality is operationalized in multiple metrics, this means that multiple levels, i.e. one for each metric, need to be defined. Where a single MEPS level is used with a generic product definition the tendency exists to set the MEPS at such level that products with the maximum possible functions under the definition can comply[77]. This means that for other products the MEPS level is too generous. In case of (multiple) allowances the problem arises that it is difficult to take into account synergies between the different functions regarding power consumption. Each of the allowances has to cover for the case that only this allowance is used which, in case synergies exist, results in a too generous total allowance when applying more than one allowance.

7.2.3. Summarizing the challenges; which of the challenges will be addressed

We can summarize the challenges for the classic approach to setting MEPS as follows. Multiple functions increase the number of product definitions unless more generic definitions are used. Each product definition has to be worded carefully to avoid circumvention of a measure by designing products out of the product definition. More generic definitions make it more difficult to set ambitious MEPS levels. Furthermore, multiple functions increase the complexity of metrics and test procedures, and in the case of using allowances problems occur with setting appropriate MEPS levels.

Changing functionality especially impacts test procedures. In order to deal with the issues, e.g. the product’s awareness of the test procedure, the test procedures need to become more complex and probably less accurate. This leads to higher costs for product testing. Furthermore, changing functionality can impact credibility when it occurs after the product has been placed on the market, e.g. through software updates, and increases energy consumption.

In the alternative approach presented in the next section we focus on the challenge related to the multiple functions.

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[77] An example related to a generic function, is the EU (network) standby regulation, see section 7.3.2.

7.3. A modular functional approach to MEPS

7.3.1. Basics of a modular functional approach

A modular functional approach consists of two parts: a generic part, which is product independent, and a specific part, which is product dependent. The generic part, which sets the standard for the functions, consists of the following steps:

- Step 1: Define the functions (or energy services) that are to be tested.
- Step 2: Define the test methods for determining the power or energy consumption for the functions, including the performance, and define the energy or efficiency metrics.
- Step 3: Set requirements for the functions, based on the metrics.

The steps of the generic part can be considered a standard setting process for one or more functions that occur in products. It combines the work of standardization organisations and regulators. In principle this generic part should cover all functions (or energy services) that are relevant for the energy consumption of products, e.g. generating heat and cold, light, connectivity.

The specific, which applies the modular functional standard to a product, part consists of the following steps:

- Step 1: Determine the functions (or energy services) of the product that are to be tested.
- Step 2: Measure the power or energy consumption for the functions according to the test methods and calculate the energy or efficiency metrics.
- Step 3: Determine whether the functions meet the requirements.

The specific part is carried out by e.g. a manufacturer or market surveillance authority to check whether a product complies with the requirements on the functions it has.

We note the following differences with the classical approach. First, the focus is on functions or energy services, not on products. So, the definition of the product has become less important. Second, in the ideal case, the modular functional approach is horizontally applicable. Once a function has been defined, it should not matter in which product this function is used. In terms of regulatory efficiency one regulation could cover a large number of product categories; an example is the EU (networked) standby regulation that covers all products in more than 30 product categories. Third, it allows for testing part of the functions of a product. This stimulates power management assuming the MEPS level is specified for the function that is tested. To meet this level, the functions that are not used, i.e. not tested, need to be powered down by the product.

The modular functional approach introduced at the beginning of this section is described as an ideal type, i.e. regulators do currently not apply the steps as indicated. We elaborate two examples of functional modules. With the help of these examples, we assess the approach and provide recommendations for further development; see section 7.4. One example is based on existing experience in EU legislation, the other is fictional. As a first example, we describe the development of networked standby regulation in the EU that has been inspired by the modular functional approach. Second, in section 7.3.3, we sketch the development of a functional module for displays. Displays are a component in ever more products not only in consumer electronics but also in white goods amongst others. But in products such as televisions and monitors, the display is the main functional component. Regarding the steps of the approach we focus on the generic part step 1 and the definition of the metric in step 2, assuming that test procedures are available or can be derived from current standards.

7.3.2. Connectivity, EU networked standby regulation

Network connectivity is available in ever more products. For some products, e.g. routers, switches, providing network connectivity is the main function and for many others network connectivity is essential to use the Internet, download software etc. Furthermore it is often possible to access or reactivate the product through the network. If all these products stay in idle or even on mode permanently to preserve the network connection awaiting reactivation or access via the network, their total energy consumption will increase significantly (Rozita and Siderius 2014). In this section we consider networked standby as a module under the modular functional approach and describe the development of the EU regulation for networked standby[78] along the steps of the generic part.

With regard to the first step, the function of networked standby is to facilitate the activation of other modes by having at least one network function active. Networked standby allows the product to be in a mode with a lower power consumption thereby saving energy.

For the second step of the generic part we first deal with the relation of the power consumption in networked standby to the function delivered. The preparatory study for networked standby in the framework of the EU Ecodesign Directive developed the concept of network availability (Nissen 2011, p. 1-13,14). Network availability is the capability of the product to resume applications after having received a trigger via the network. Network availability is expressed in the time that it takes to resume an application, the *resume time*. It is a performance parameter expressing what the end-user or other products expect from the product being in networked standby. Network availability includes the following aspects:

- connectivity: reaction latency, complexity of network integrity communication;
- configuration: the number and type of network connections;
- quality-of-service: redundancy, security, scalability.

Although resume time is a clear concept, measuring resume time is not easy and would require specific instructions for individual products, something to be avoided in a modular approach. The implementation in the framework of the EU Ecodesign Directive opted for a simplified approach, by using two levels of network availability – high and low network availability – and defining a short list of high network availability (HiNA) products. Router, network switch, wireless network access point, hub, modem, VoIP telephone and video phone are HiNA network products. Furthermore, products with the functionality included of a router, network switch, wireless access point or a combination thereof are defined as products with HiNA functionality[79]. All other networked products, such as personal

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[78] OJ L 225, 23.8.2013, p. 1-12.

[79] The reason for this distinction is that products with HiNA functionality – contrary to HiNA products – need to comply with the EU standby regulation when the HiNA functionality is not used or switched off.

computers, audio equipment, televisions and white goods with network connection, are considered to be low network availability (LoNA) products.

The metric is the power consumption in networked standby. The measurement method specified by the EU regulation deals with the issues of multiple network connections. The product shall comply with the required value for all types of available network connections when one network connection is present. If there is more than one network port of a certain type of connections available, one port is randomly selected for testing leaving the others disconnected. For the general conditions and set-up of measuring power consumption in (network) standby we refer to IEC 62301, second edition.

To prepare for the setting of requirements – the third step in the generic part – the preparatory study took into account 21 product categories from 4 general product groups: computer equipment, network equipment, consumer electronics and imaging equipment. **Table 7.1** provides an overview of power consumption in networked standby of best available products in 2011.

Table 7.1 Power consumption in networked standby – best available products (2011)

Product	Power consumption in networked standby (W)	Resume time (category)	Type of network connection; remarks*
Desktop computer	1.65	LoNA	S3+WOL
Notebook computer	1.25	LoNA	S3+WOL
Notebook computer	< 1	LoNA	S4/S5+WOL
Network Attached Storage (Home NAS)	2.3	LoNA	
Inkjet printer	3.7	LoNA	WLAN, USB
Large format printer	9.7	LoNA	
Home Gateway	3.3 – 8.1 11	HiNA	Depending on configuration With DOCSIS modem
Complex set-top box	4.5 – 7.5	LoNA	Cable - Satellite
Mobile/handheld products	< 1	HiNA	WLAN

* S3-S5 refer to ACPI states: S3=suspend to RAM; S4=suspend to disk; S5=soft off. WOL= Wake On LAN. WLAN=Wireless LAN. USB=Universal Serial Bus. DOCSIS=Data Over Cable Service Interface Specification.
Source: Siderius (2012)

Since differentiation between the types of network connection would have destroyed the horizontal approach, the requirements needed to accommodate the most power hungry network connection. **Table 7.2** shows the requirements for networked standby that were finally adopted under the EU ecodesign regulation.

Table 7.2 Power requirements for networked products in networked standby

Networked product	Tier 1 (1-Jan-2015)	Tier 2 (1-Jan-2017)	Tier 3 (1-Jan-2019)
HiNA network products Networked products with HiNA function(s)	12 W	8 W	8 W
other networked products (LoNA)	6 W	3 W	2 W

Source: OJ L 225, 23.8.2013, p. 1-12.

7.3.3. Displays

A display can be an individual product, e.g. a television or a monitor, but also a component of a product that has another primary function than displaying images, e.g. a display on a refrigerator or washing machine. As an example of the application of the functional modular approach, in this section we develop a display module. Ideally, this module would be used for evaluating the display function of a range of products, including products where the display function is not the main function. **Figure 7.4** shows a generic model for CE and ICT products with the components that are relevant for displays in boxes.

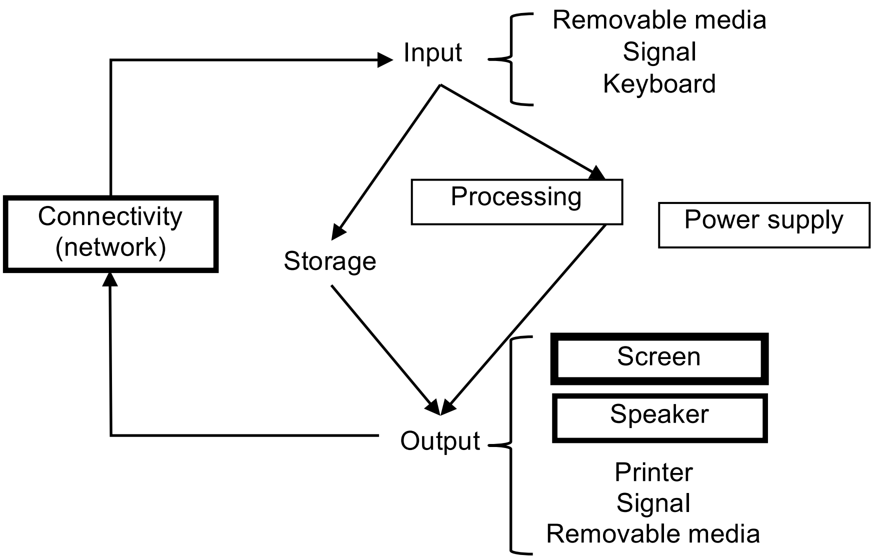

Figure 7.4 Generic model CE and ICT products applied to displays; arrows indicate data flows

Following the generic steps, the main function of a display in active mode is to provide information or entertainment. However, it is difficult to operationalize this into a metric, also because the fulfilment of this function not only depends on the display but also on the content[80]. Therefore the energy service is used to define a metric; this service is displaying (moving) images on an integrated screen. Other services can be connectivity and producing the accompanying sound with the images; power supply and processing are supporting functions.

For the second step of the generic part we concentrate on the metric for the display function; regarding the method for measuring the power consumption we refer to IEC 62087, third edition. The following characteristics determine the power consumption (Park et al. 2011): screen area, resolution and brightness. Since the brightness is set by the measurement method, we will not consider this aspect. The resolution influences the power consumption for processing but is also related to screen size: larger screens are more likely to have higher resolution. The power consumption for processing is related to the resolution and other image processing aspects, e.g. scaling, quality improvement. With televisions the processing of the broadcast signal is done in the television, with monitors a large part of the processing can be done outside, e.g. by the graphic card of the computer to which the monitor is connected. To arrive at an efficiency metric we need to relate the power consumption of the display to the energy service. We choose the screen area to represent the energy service, so $P_{display} = f(A_{screen})$. If the power consumption is proportional to the screen area, we can derive the following metric: $\alpha_{screen} = P_{display}/A_{screen}$ [W/m^2]. If $f(A_{screen})$ is a more complex function we can use an energy efficiency index as metric: $EEI = P_{display}/f(A_{screen})$. The choice for a metric can be made based on further technical analysis of the product and/or by analysing data on the relation between power consumption and – in this case – screen area. We look at data for televisions and monitors collected from manufacturers and independent laboratories for the revision of the television regulation in the EU; see **Figure 7.5**. All measurements were obtained using the dynamic test sequence of IEC 62087, third edition. From this data we learn that the metric α_{screen} is too simple and that the following function provides a better fit: $f(A_{screen}) = 3.3526\times(A_{screen})^{0.7745}$. Thus the metric becomes: $EEI = P_{display}/3.3526\times(A_{screen})^{0.7745}$.

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[80] Also the power consumption of a display can depend on the content, i.e. on the percentage lighter or darker parts in the content expressed as APL (average picture level). Therefore in IEC 62087, third edition, displays are tested with a standardized content with an APL approximately equal to the average APL of various broadcast and internet content worldwide.

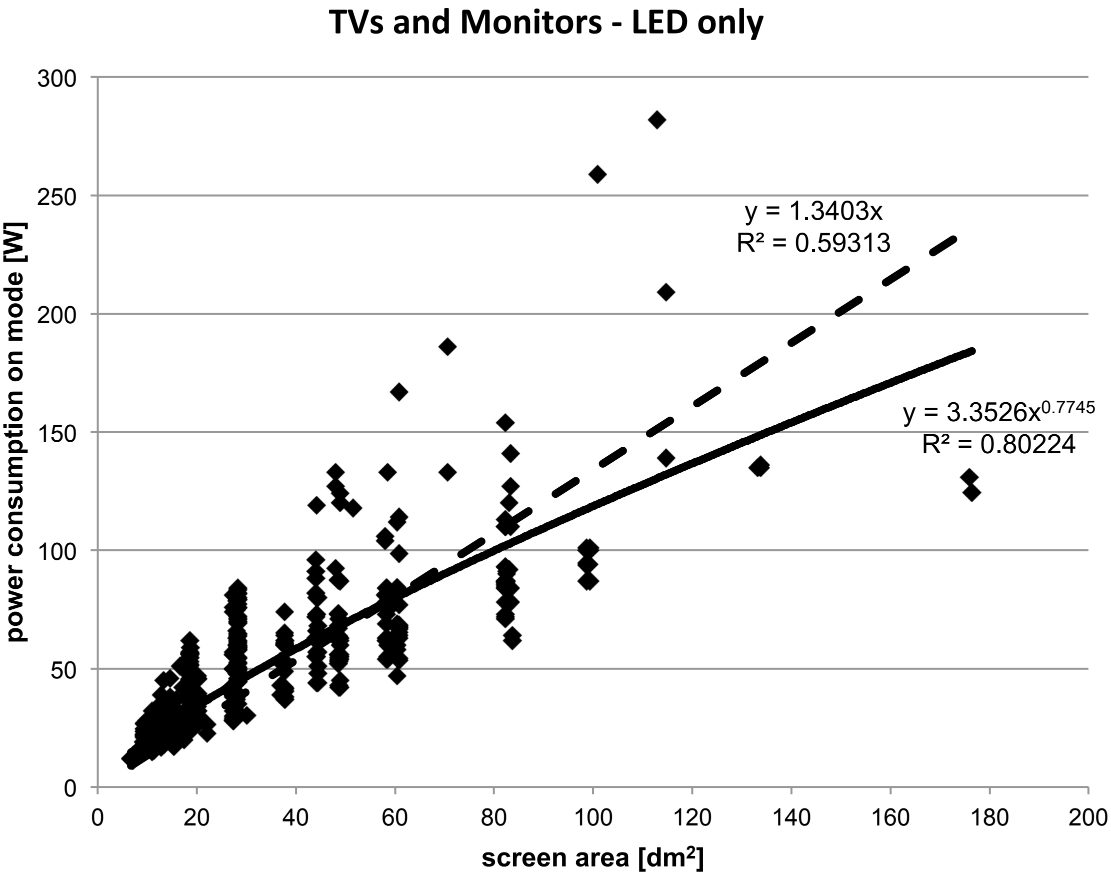

Figure 7.5 Displays: relation between power consumption and screen area

In the third step requirements for the function are set. As indicated, this involves more work than we can describe here, e.g. a technical-economical analysis and/or market analysis. Assuming that the MEPS level is set at EEI_{MEPS}, we can use this level in different ways. For display products the EEI_{MEPS} can be used for regulation based on the on mode: products with higher EEI than EEI_{MEPS} are not allowed on the market. If we consider a display component or if we want to regulate the total energy consumption (TEC) based on the power consumption in different modes, then we can calculate the allowed power consumption by $P_{display} = EEI_{MEPS} \times 3.3526 \times (A_{screen})^{0.7745}$. The rationale for using the EEI_{MEPS} from monitors and televisions for display components as well is that these components should not be less efficient than an entire monitor or television product.

7.4. Discussion, conclusions and recommendations

We started this chapter by describing and analysing some of the problems that the current methodology for setting minimum efficiency performance standards (MEPS) and labels faces. Due to rapid developments in electronics, software and networks, ever more products are connected to a network, have multiple functionality and can change functionality. Multiply functionality, including the function to connect to a network, increases the complexity of the product definition, metrics and test procedure. We introduced a modular functional approach to solve the problem of multifunctionality and to move away from setting standards for individual products and instead focus on defining and evaluating functions that can be present in many products.

The advantages of a modular functional approach mainly lie in increasing the regulatory efficiency, i.e. one 'horizontal' regulation can cover a large number of product categories, including products that are not yet on the market[81]. Also, this can increase the effectiveness of product energy policy because products that in the classical approach never would get an individual measure would be covered by a horizontal measure. Regulating (networked) standby power consumption in the EU is a typical example showing these advantages. Because of the focus on (network) standby, the product definitions in this regulation can be generic; in fact several of them indicate product categories only. Second, the separate energy savings of many products covered by this regulation would not justify preparing and adopting an individual measure. Furthermore, a modular functional approach can provide for a larger market volume to develop solutions for which then will be cheaper. Finally, it can stimulate power management, if part of the functions of a product are tested and the MEPS level is specified for the functions that are tested.

The examples in the foregoing section also showed disadvantages of the approach. First, the modular solution for networked standby that is to be applied to a broad range of products has as drawback that the requirements are set to accommodate the most power hungry type of connections while not all products may have this type of connection. Comparing the values in **Table 7.1** with the requirements in **Table 7.2** shows that certain products can achieve lower power levels than required but are not regulated to do so.

A second issue is the development of definitions, metrics and test methods for functions or energy services. Although it is not the objective of a modular functional approach to

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[81] This assumes that a horizontal measure is legally possible which is e.g. not the case under the current US DOE appliance standards programme.

take on board all functions of all products, the main functions should be covered. The examples in section 7.3 included network connectivity and the display function, but ignored the processing function that will become more important with increasing screen resolution, and is central to many other electronic products such as set-top boxes, computers and home gateways. However, as was indicated in chapter 5, to develop a metric and test procedure for processing is not an easy task for personal computers and graphic cards, let alone for processing in general[82].

Related to the foregoing, it remains difficult to operationalize the functionality of a product. This is true for a classic product like a refrigerator of which the function is food preservation but for which the efficiency metric is based on the energy service, i.e. the energy to keep a certain volume at a certain temperature. However, operationalizing functions of electronic products like entertainment and providing information is an even greater challenge. This includes bridging the difference between the energy service and the functionality. In general MEPS take the needs of the user reflected in the performance of the products on the market as given; if a refrigerator is equipped with a display of a certain size and resolution, the MEPS will not question whether this size or the resolution is necessary for the function of providing information to the user. However in some other cases, electronics and software do bridge the difference between the energy service and the functionality: automatic brightness control adjusts the brightness of a display to the ambient light level, and auto power down switches the product off when nobody is using it.

Third, we assumed that functions can be tested separately; this might not always be the case, especially for products with many and interrelated functions. In that case, the functions to be tested need to be chosen carefully; it is not realistic to test every single (auxiliary) function.

Finally, the modular functional approach does not bring advantages for appliances with a single main function, e.g. cold appliances, washing machines, water heaters; these appliances are already assessed by a functional approach, i.e. of their main function. However, an air conditioner that can both heat and cool – a heat pump – can be tested

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[82] A further complication is that for virtual products the processing is done outside the product, in data centres.

and evaluated separately for these two functions. Also, section 7.3.3 illustrated how a (large) display of a refrigerator could be dealt with.

Taking the pros and cons into account, we conclude that a modular functional approach can be useful to extend the range of MEPS by providing for a horizontal approach across products for certain functions, e.g. connectivity and display of information. However, the extension of the range, i.e. the inclusion of more product categories, has to be balanced against the drawback that requirements cannot be fine tuned for individual products.

Electronic products, that mostly have multiple functions, seem to be the ideal products to apply a modular functional approach to. However, without at least the development of a metric and test procedure for the processing function, the modular functional approach cannot be a full replacement of the current methodology for electronic products. Another functional module to be developed is a storage module.

The first recommendation following from the foregoing is to develop a metric and test procedure for the processing function. Since processing performance is a key function of electronic products that are currently subject to MEPS and labels, such as personal computers and servers, the results from this development would benefit both approaches. The second recommendation is to investigate the situations where functions cannot be tested separately; amongst others this should lead to suggestions how to deal with synergies. Broadband equipment is a good candidate to start the investigation. The third recommendation is that policy makers should look at horizontal opportunities for applying MEPS by means of a single functional module across products. This requires a shift of focus: from setting full MEPS for a few products to setting partial MEPS for a large number of products. The energy service ‘generating light’ could be an opportunity to develop a functional module that could be applied to a variety of lamps[83], from household lighting to commercial and street lighting. Currently, lamps are covered by a large number of different types of requirements that are not based on ‘generating light’ but on e.g. caps or technology[84].

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[83] Note that with current LED technology the definition of ‘lamp’ needs to be revised also.

[84] See e.g. the ecodesign regulation on “tertiary lighting” (OJ L 76, 24.3.2009, p. 17-44).

8.

Conclusions, discussion and recommendations

8.1. Summary of findings

The current level of primary energy demand in the world is not sustainable; it results in increasing CO_2 concentration, decreasing energy security and increasing energy prices. The effects of climate change and resource depletion threaten the way we live on this planet. Efficiency improvements in end-uses could deliver two third of the reduction on primary energy demand that is needed to achieve a level of energy demand that will stabilize greenhouse-gas concentration at 450 ppm CO_2-eq. Such a level is considered to have a 50 % chance of meeting the goal of limiting the global increase in average temperature to 2 ^{0}C in the long term, compared with pre-industrial levels.

This thesis is about polices that tap into this end-use efficiency potential, more specifically about mandatory policy measures on product conformity (minimum efficiency performance standards or MEPS) or product information (energy labels). MEPS and energy labels are the most widely used product policy measures for energy efficiency. The foregoing chapters of this thesis addressed some of the challenges for these measures, with the aim to increase the effectiveness of the measures and the efficiency of the process of preparing and adopting measures. The main findings are summarized in this section.

Learning from other countries can be an important way to increase the effectiveness and efficiency of policy measures. However, the comparison needs to be done in a fair way. Chapter 2 (***International benchmarking of products for policy makers***) first demonstrated a method how to compare energy efficiency of products across countries. Normalisation of data took into account variations that are due to the way in which data on energy performance was measured in each country. These included variations due to performance aspects, environmental (test) conditions and differences in test methodologies. Second, by applying mapping & benchmarking to three products (refrigerator-freezers, washing machines and laundry-driers) the results generally showed an improvement in efficiency over time of these products. Refrigerator-freezers improved with around 0.02 kWh/adjusted litre, year per year, washing machines (EU) and laundry-driers with 0.01 kWh/kg per year. Refrigerator-freezers in the EU are amongst the least efficient in the world, but also have, apart from China, the lowest unit energy consumption (kWh/year)[85]. For laundry driers efficiencies worldwide converged to 0.7 kWh/kg. For washing machines in the EU, the energy consumption of the standard wash cycle stayed the same between 2006 and 2009, whereas the average specific capacity increased by 0.16 kg/year. Therefore, the efficiency improvement in this period was due to an increase in capacity and not due to lower energy consumption.

The Japanese Top Runner programme to improve energy efficiency of products has attracted attention from policy makers world wide. Chapter 3 (***Top Runner and Ecodesign***) showed that policy programmes that seem to be (very) different in the end have more in common than is sometimes suggested. Both Ecodesign and Top Runner contribute significantly to the energy efficiency targets in their jurisdictions. It was estimated that Ecodesign (and Energy Labelling) measures save 16 % of EU household electricity consumption in 2020. For Top Runner the savings amounted to 11 % of Japanese household electricity consumption in 2009. Both schemes are dynamic, i.e. they have a tiered approach and/or regular reviews, but the Top Runner programme is more explicit in advertising its dynamic nature. However, the dynamic nature of Top Runner does not mean that the programme has short review cycles. Ecodesign could use more explicitly a top runner approach, whereas Top Runner could benefit using a real *minimum* efficiency performance standard instead of a fleet average. Thus manufacturers would no longer need to provide (commercially sensitive) sales data and it would open the Top Runner programme for products where the market situation is less clear. For both schemes the manageability will increasingly become a challenge because the number of products increased, the type of products changed and the schemes have been successful so that they attract more attention from stakeholders.

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[85] **Figure 2.3** and **Figure 2.4** show data until 2008-2009. The benchmarking report for refrigerator-freezers has been updated recently with data until 2010-2011 which confirm these findings (4^E M&B Annex 2014).

Life cycle costs (LCC) have a pivotal role in the methodology for setting MEPS. Earlier research showed that LCC calculations for setting MEPS should use dynamic costs. Dynamic costs can be modelled by experience curves, indicating that product cost is decreasing in time with increasing cumulative production. Chapter 4 (***The role of experience curves for setting MEPS***) demonstrated how experience curves can be integrated into LCC calculations. Experience curves provide an estimate for the experience ratio, the reduction in costs when cumulative production volume is doubled. Chapter 4 explored two ways to integrate the concept of experience curves in to LCC calculations for setting MEPS: the ecodesign approach complying with the rules of the EU Ecodesign Directive, and the top runner approach. The ecodesign approach estimated the cost reduction at the time the measure should come into force for each of the design options to improve efficiency. Using these values, a LCC curve was drawn and least life cycle cost point was determined. In the top runner approach, the new MEPS level was set by the top runner product at the time of the analyses. Then it was calculated how much time was needed for cost reduction to bridge the gap between the least life cycle costs at the time of analysis and the life cycle costs of the top runner product. The new MEPS level could come into force after that time elapsed. For both laundry driers and refrigerator-freezers the experience curve approach resulted in more stringent MEPS levels than the current approach used in Ecodesign. The savings were estimated to be at least twice the savings of the current approach. The top runner approach allowed the same, stringent requirements to be set earlier. A consequence is that the product price in the top runner approach is higher.

The relation between price and energy efficiency is the basic rationale for using LCC calculations to guide the setting of MEPS. For laundry driers and refrigerators chapter 4 showed in general a correlation between price and energy class: the higher the energy label class (the more efficient the product) the higher the price. However for televisions, the other product studied in chapter 4, there seemed to be no such correlation. Chapter 5 (***Setting MEPS for electronic products***) explored the relation between price and efficiency for 15 consumer electronic (CE) and information and communication technology (ICT) products, including televisions. In general price did not relate to the efficiency of the product if also performance and time were taken into account. Exception was the internal power supply for computers where each additional efficiency percentage point added €$_{2010}$ 4 to the price. The price of electronic products with comparable performance decreased over time. For products where data allowed fitting the relation, the price decreased exponentially with an average time constant of -0.30 per year, meaning that every year the products on average became 26 % cheaper. If no relation exists between price and efficiency then LCC calculations cannot guide the setting of MEPS. Chapter 5 presented an alternative approach based on the variation in efficiency of products on the market and the improvement of efficiency over time. The MEPS level is set by the level of ambition, i.e. the percentage of products that should stay on the market. The average price decrease then guides the entry into force date of the measure. Another characteristic of CE and ICT products is that product development is fast. If such product development also results in improvements in efficiency, it might be that setting MEPS is not needed. The concept of the policy action window (PAW) was proposed as an indicator of the time available for policy making and therefore an indicator of the appropriateness of setting mandatory MEPS. The PAW has been defined as follows: $PAW = 2\ sd_{eff,avg}/EIC$ where $sd_{eff,avg}$ is the average standard deviation of the efficiency over a number of years and EIC is the efficiency improvement coefficient, i.e. the average improvement of the efficiency over time. Short, i.e. less than three year, PAW values were found for graphic cards, network attached storage, network switches and televisions. Since the process of setting MEPS can easily take three years, this means that policy makers should be cautious in preparing measures for these products unless of course other arguments exist.

With ever more measures or revision of measures being prepared, the efficiency of the process itself – expressed in the duration of the process – requires due attention. Chapter 6 (***Analyzing delays in preparing and adopting ecodesign and energy labelling measures***) found that for EU ecodesign and energy labelling measures the time to prepare and adopt a measure was on average 56 months and 71 months for the 12 measures published since 2012. This time is significantly larger than the planning suggested by the Commission, which is 47 months. The process to establish Top Runner standards is estimated to take 30 months, and the DOE rulemaking process for appliance standards 36 months. However, the DOE rulemaking process has faced delays that increased process time to 54 months. The delays in the EU process were translated into lost energy savings by multiplying the delay in years for each product with the estimated savings per year. This amounted to cumulative lost savings of more than 7000 PJ for boilers and water heaters and 263 TWh for other products. Delay factors included process organization and capacity at the Commission, quality of the preparatory study and available data for a measure, and technical complexity and political sensitivity. The impact of process organisation could be quantified by using the number of staff changes at the Commission for a product as a proxy: having at least one staff change adds on average 15 months to the process. The process can be improved and the delays can be reduced. It was suggested that – on average – a three-year schedule is a reasonable time span.

Finally, chapter 7 (***A modular functional approach to product efficiency standards***) investigated another challenge that the process of setting MEPS faces: the increasing complexity of products that are to be regulated. Due to developments in hardware, software and networks, products have multiple functions, can change functions through software updates and ever more products are connected to a network. This makes the definition of a product, which is the basis for setting MEPS, more complex. A modular functional approach was proposed that focused on defining functions that could be applied horizontally, i.e. for a broad range of products. Although the example of the EU networked standby regulation showed that the principle can be applied, the modular functional approach cannot yet fully replace the current process of setting MEPS. Further development, especially regarding a processing function, is needed.

Through the various chapters several cross-cutting themes emerged; three of them are discussed in the rest of this section. The first is that setting MEPS is not only about setting levels, requirements that products must meet, but also about the timing of these requirements. Or said otherwise: setting MEPS involves determining a point in the energy efficiency – time space. The timing aspect often gets considerably less attention in the literature. In various chapters of this thesis it is shown to be an important aspect. For the Top Runner programme, the timing is in principle the only variable that is left for negotiation because the MEPS level is set by the Top Runner product. Timing is also a crucial aspect when dealing with electronic products. Because for electronic products price is related to the duration the product is on the market, the timing of a measure is critical in ensuring that products that meet the requirements are also affordable. Finally, the timing refers to the policy process: if the efficiency improvement of a product is faster than the policy process, it might not be appropriate to set MEPS. The policy action window was introduced to enable relating the speed of efficiency improvement to the duration of the policy process. Delays in the process increase the duration of the process; this makes it more difficult for some products to stay within the policy action windows.

A second theme that recurs in several parts of this thesis is the reflection upon the criteria for setting MEPS levels: the life cycle cost approach and the top runner approach. Whereas the life cycle cost approach is an economic criterion, the top runner approach shifts the attention to the most efficient products on the market to set the MEPS level. Thus the top runner approach hints more at innovation to drive efficiency than economics. As chapter 4 showed, the top runner approach can deliver more energy savings albeit at higher product price. The top runner approach is especially suitable for electronic products where life cycle costs are not a suitable criterion to guide the settings of MEPS. The top runner product sets the MEPS level and the timing is determined by the (expected) price decrease. The top runner approach could also be used between countries. First, the market that is looked at to find the most efficient product can be larger than the country for which the MEPS is set. Second, it could be understood as a top runner approach of policies: governments then would choose the most stringent level worldwide as the next level for their policies. The mapping and benchmarking methodology as described in chapter 2 would enable both.

Third, electronic products are a recurring theme. Electronic products are relatively new when looking at the history of mandatory MEPS and labels. This might be due to the fact shown in chapter 5 that life cycle costs that are used for the classical MEPS products are not a useful guide for setting MEPS for electronic products. Furthermore, especially electronic products offer multiple functions and are connected to a network which complicates the setting of MEPS. Chapter 5 offered a solution to guide the setting of MEPS for electronic products. Chapter 7 presented a solution in theory to deal with multiple functions. However, practical application to electronic products is hampered by the lack of a metric and test method for the processing function of electronic products. Which, as such, could also be a reason for the small number of MEPS and labels. Finally, electronic products are truly globally traded products that thereby stimulate the development of global test methods and standards.

8.2. Conclusions and discussion

8.2.1. Conclusions

This thesis set out to address some of the challenges for product energy policy related to the effectiveness of the measures and the efficiency of the process. The overarching conclusion, based on the results in the chapters 2 to 7 is that several of the challenges can be addressed. MEPS can be made more effective by integrating experience curves into life cycle cost calculations and by applying a top runner approach including learning from other countries i.e. using the most stringent MEPS level worldwide as the next standard. The process can be made more efficient by taking into account technical complexity and political sensitivity. Products that have a lower than average technical complexity and political sensitivity could have a shorter or stricter process, whereas especially for products that are both technical complex and contentious, the process could be more elaborate. Furthermore, the policy action window (PAW) can be used to make the overall process more efficient, i.e. to avoid spending time on policy making for products that improve efficiency without measures (business as usual) fast enough.

More specific conclusions are the following. Learning from other parts in the world can be an important source for addressing challenges. However, a necessary condition is that fair comparisons can be made between results in different parts of the world. The dynamic aspect of policies, i.e. the regular update of MEPS and labels, seems to be more important than the choice for a specific policy. Results for refrigerator-freezers suggest that in the long run both a policy strategy where MEPS are prominent and a policy strategy where a mandatory energy label is prominent can provide for increasing efficiencies.

Both Ecodesign and Top Runner contribute significantly to the energy efficiency targets set by the European Commission and the Japanese government respectively. Although the appeal of the Top Runner programme in Europe seems to a large degree conceptual, the conclusion is that a top runner approach can increase savings because it allows for more stringent MEPS, regarding level and/or timing. The current Ecodesign Directive allows for applying elements of a top runner approach, but the least life cycle cost criterion is the main guidance for setting MEPS. However, the Ecodesign Directive foresees no solution in case no relation between the price and the efficiency of a product exists, and therefore the LCC approach cannot be applied.

Using experience curves is possible in the Ecodesign framework and provides more realistic price estimates. For products that also have an energy label, the energy label classes can be used as a proxy for design options.

Although CE and ICT markets develop at a high pace, the opportunities for setting MEPS vary. Given the time necessary to prepare and adopt a measure, i.e. at least three years, PAW values suggest that setting MEPS for graphic cards, network attached storage products, network switches and televisions probably will not deliver more savings than business as usual.

The process of preparing and adopting ecodesign and energy labelling measures in the EU is to a large degree custom-made for each measure. Although the sequence of steps is prescribed, the documents and the processes in the steps are flexible and reinvented for each single measure. This makes the process for an individual measure adaptive, but severely complicates the management of the total process for all measures. Since the number of measures has not only increased in the EU, but also in the US and Japan, manageability is a concern for all three schemes. Furthermore, the efficiency of the process, expressed in terms of the duration of the process, influences the effectiveness: a shorter process results in more savings, since measures can come into force earlier.

A modular functional approach can be useful to extend the range of MEPS by providing for a horizontal approach across products for certain functions, e.g. connectivity and display of information. Electronic products, that mostly have multiple functions, seem to be the ideal products to apply a modular functional approach to. However, without at least the development of a metric and test procedure for the processing function, the modular functional approach cannot be a full replacement of the current methodology for electronic products.

8.2.2. Discussion

In the introduction it was stated that explicit theory on product energy policy is scarce. This statement illustrates both the strengths and the weaknesses of the research presented in this thesis. Looking at various angles to product energy policy, this thesis contributed to the knowledge on product energy policy, including useful tools for policy makers, such as improvements to the LCC methodology and the concept of the policy action window. However, the lack of theory also means that this thesis could not contain thorough hypothesis testing. In that respect the findings and conclusions are only a first step in a longer process. Several conclusions are more or less based on case studies, i.e. based on results related to a few products (cold appliances, washing machines, laundry driers and televisions). However, in the meanwhile the Mapping&Benchmarking Annex has covered other products, e.g. transformers and commercial cooling[86]. For CE and ICT products a larger number of products was included, but the data was based on a single source from a single country. Another aspect that this thesis put different emphasis on in the different chapters is the 'why' question. Why questions that only received marginal attention are: why do product energy policies and their results differ in different parts of the world, why is the set-up of Ecodesign and Top Runner programmes different, why is the efficiency of CE and ICT products not related to price? Answering why questions requires a different type of research, but also first the statements to which the why questions relate needed to be ascertained. On the contrary the 'why' of the delays in preparing and adopting EU ecodesign and energy labelling measures was looked at in detail. In this case the delays were obvious and from the start the focus could be on the why question.

Obviously, this thesis could not address all challenges that product energy policy faces. This section shortly discusses two other major challenges that would require and deserve a separate study. The first is market surveillance. Effective market surveillance is necessary for a level playing field and to ensure that savings are not only achieved on paper but also in practice. Market surveillance in the EU is complicated because it is a Member State competence. Because several Member States, e.g. Germany, have

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[86] See the Mapping&Benchmarking website of the IEA 4^E implementing agreement: mappingandbenchmarking.iea-4e.org.

delegated this competence to a lower administrative level, this means that in the EU more than 50 market surveillance authorities need to communicate, cooperate and coordinate to ensure effective surveillance. It is clear that with an increasing number of measures coming into force, the complexity multiplies. Effective and efficient market surveillance relates to test methods for determining compliance, the requirements in the measures, the setup and structure of measures, the (legal) barriers for cooperation between Member States, market monitoring etc.

The second challenge is the relation with other energy policies. This comes in two variants. First, the relation of MEPS and energy labels to other product policies, e.g. information campaigns to change user behaviour. Second, the relation between products and systems. From several ecodesign preparatory studies, e.g. for electric motors (Almeida et al. 2013), it is clear that more energy savings can be achieved with a systems approach than with a product approach only. However, the current scope of EU ecodesign and energy labelling is products. A way forward could be a modular approach where the MEPS for individual products can be easily combined to MEPS for a system. Such an approach would also be applicable for buildings where both building requirements and requirements for products like boilers and water heaters exist.

Finally, we discuss the type of goal for EU product energy policy. The goal of EU product energy policy is saving energy, using less energy. However, the interpretation of this goal depends on the reference that is used. This can be the energy consumption from a reference year in the past, as is the case when CO_2 emission reduction goals are formulated, or a reference value in the future, e.g. the consumption that would occur without the policy. It is clear that using a reference in the future can result in the situation where both energy is saved (compared to the future reference year) and more energy is used (compared to a reference year in the past). Since MEPS and energy labels only target *product* characteristics that influence the energy consumption and not the number of products sold or the use of the product[87], the savings can only be related to a reference where all other aspects than the efficiency are assumed to be kept the same. Estimates for savings from EU ecodesign and energy labelling measures in chapter 3 suggest that total savings are not large enough to reduce the absolute level of total energy

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[87] Exception may be requirements that prescribe default settings for the product.

consumption. Aiming for products that have (nearly) zero energy consumption (Siderius and Brischke 2011) would at least regarding energy consumption during use (almost) cancel out the effects of the number and the use of products. Certainly for products or components that have a small energy consumption per unit but are expected to increase dramatically in numbers, e.g. to provide network connection, this could be an effective strategy. Furthermore, it is noted that in the EU the goal of product energy policy is not quantified. It is indicated in the Energy Efficiency Plan (European Commission 2011) that ecodesign and energy labelling measures contribute towards the EU 2020 goals, but not how large this contribution should be. On the contrary, in the US President Obama set a specific goal for the contribution of appliance and building standards to CO_2 emission reduction in 2030 (Executive Office of the President 2013).

8.3. Recommendations

8.3.1. Policy recommendations

The findings and conclusions in the foregoing chapters result in a number of policy recommendations. These can be used in further development of MEPS and energy labeling measures and the process to prepare and adopt these measures. The recommendations are addressed to policy makers, including experts working at national level, EU level, NGOs and industry associations.

A general and obvious recommendation is to keep in contact with and to learn from other schemes in the world. Information exchange, coordination of test methods and MEPS levels, and full harmonization of test methods and MEPS levels are successive steps to increase collaboration between countries. This will become more useful and necessary because ever more products are produced for a global market, not only electronic products but also white goods. More specific policy recommendations are organized by chapter.

Chapter 2 (***International benchmarking of products for policy makers***):

- Policies should also be based on product energy consumption and not (only) on product efficiency. Although this does not guarantee reduction of energy consumption compared to a reference in the past, it counteracts the tendency to increase efficiency by increasing the capacity of products. Chapter 2 suggested that a maximum energy consumption cap is possible for household refrigerators. Policy makers should investigate this option also for other products.

- The dynamic aspect of policies is important. Therefore a regular revision of MEPS and energy labels is recommended.

Chapter 3 (***Top Runner and Ecodesign***):

- The Top Runner experience shows that the name of a programme can be an important contributor to its success and communication. Therefore, policy makers should pay attention to the name of the MEPS programme.
- Manageability of product energy policy programmes needs more attention from policy makers. This refers to the selection of products (work programme), the organization of the process for preparing and adopting individual measures, including staffing and sourcing of experts, and the involvement of stakeholders.

Chapter 4 (***The role of experience curves for setting MEPS***):

- Dynamic pricing, e.g. through experience curves, should be integrated in LCC calculations. As a start, the values for experience ratios found in literature can be used. However, it is recommended to regularly measure and update these values.
- Energy label classes are a good proxy for design options. In the EU, for products that have both an energy label and ecodesign measures, energy label classes should be used to structure ecodesign measures.
- The top runner approach is a simpler alternative to the often elaborate least life cycle cost calculations. Policy makers should consider using the top runner approach for products, certainly for those products where differences in costs between the design options for increased efficiency are small.

Chapter 5 (***Setting MEPS for electronics***):

- Life cycle cost calculations should not be used for setting MEPS for CE and ICT products; at least not as the main mechanism. For these products the policy ambition, expressed in the percentage of the products on the market that should be able to meet the MEPS, can guide the setting of MEPS. The timing of the measure can then be decided based on the price decrease rate.

- It is recommended that policy makers use the policy action window concept in deciding whether it is useful to start preparing an efficiency measure for a certain product or use alternative policies. Furthermore the policy action window can be used to set priorities among potential products.

Chapter 6 (***Analyzing delays in preparing and adopting ecodesign and energy label measures***):

- It is recommended to adapt the duration of the process to the characteristics of the product with the aim to reduce the time for preparation and adoption to three years (on average). Products that have a lower than average technical complexity and political sensitivity could have a shorter process.
- Measures should become more standardized. The order of the parts of a measure such as definitions, requirements including timing, test methods and verification procedure, should be the same for all measures. Where possible also the same wording should be used.
- Regarding the EU process, comitology, although not perfect, should be kept for ecodesign measures and be reintroduced for energy labeling measures.

Chapter 7 (***A modular functional approach to product efficiency standards***):

- It is recommended to develop more functional modules that can be horizontally used, e.g. for the energy service ‘generating light’.
- Policy makers should look at horizontal opportunities for applying MEPS by means of a single functional module across products.

8.3.2. Recommendations for further research

Recommendations for future research first of all point to the topics of product energy policy that this thesis did not address: market surveillance, and relation with other policies are important themes that deserve further attention. The topic of market surveillance includes both the improvement of market surveillance itself and improvement of measures to enable more effective and efficient market surveillance.

Regarding the relationship with other policies, an important question is how measures can be designed to reinforce each other.

Management of product energy policy programmes is a further area that needs attention; chapter 6 paid some attention to the manageability of the process. The large number of measures that already are in place (and therefore will need revision at some point in the future), and the number of products for which measures are intended to be prepared beg the question whether a more standardized format of measures is possible and which benefits this would bring. Worldwide cooperation and possibly coordination of measures is another management aspect that can bring benefits but also has drawbacks. Chapter 2 touched on some of these issues related to mapping and benchmarking, but this topic deserves more attention, e.g. with respect to the cultural differences related to policies.

Chapter 7 introduced a modular functional approach to setting MEPS. However, the focus was more on the modular aspect than on the functional aspect. Currently, most MEPS are not based on a functional assessment, but at best on the energy service produced by the product. Further research is recommended to explore whether the functionality of products could be used more as a basis for product energy policy.

In the top runner approach and certainly for CE and ICT products, innovation is an important driver. Thus, the relation between product energy policy and (product) innovation policy is an area for future research. How is the relation between innovation and efficiency to be understood? And, assuming there is generally a positive relation, can product energy policy help innovation and especially can it accelerate innovation?

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Symbols and abbreviations

ACPI	Advanced Configuration and Power Interface (specification)
AdCo	administrative cooperation
ANOPR	Advanced Notice of Proposed Rulemaking
APL	average picture level
BAT	best available technology
BAU	business as usual
CCFL	cold cathode fluorescent lamp
CE	consumer electronics
CEC	Californian Energy Commission
CF	Consultation Forum
CPU	central processing unit
COP	coefficient of performance
CRT	cathode ray tube
DOCSIS	Data Over Cable Service Interface Specification
DOE	Department of Energy (US)
DVB	Digital Video Broadcasting
EC	European Commission
EEC	European Economic Community
EEI	energy efficiency index
EFF	efficiency
EIC	efficiency improvement coefficient

ELCC	equal life cycle costs
EP	European Parliament
EU	European Union
FL	front loader (washing machine)
FP7	7th Framework Programme
FPD	flat panel display
fps	frames per second
GEA	Global Energy Assessment
GLM	generalized linear model
GPP	green public procurement
GTOPS	giga theoretical operations per second
HDD	hard disk drive
HICP	harmonized indices of consumer prices
HiNA	high network availability
IC	integrated circuit
ICT	information and communication technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IO	input-output
IP	internet protocol
IPCC	Intergovernmental Panel on Climate Change
ISC	interservice consultation

ISO	International Organization for Standardization
LAN	local area network
LCC	life cycle costs
LCD	liquid crystal display
LED	light emitting diode
LLCC	least life cycle costs
LoNA	low network availability
MEErP	methodology for ecodesign of energy-related products
MEPS	minimum efficiency performance standards
METI	Ministry of Economy, Trade and Industry (Japan)
MFD	multi-function devices
MTOPS	mega theoretical operations per second
NAS	network attached storage
NGO	non-governmental organization
NOPR	Notice of Proposed Rulemaking
OJ	Official Journal (of the European Union)
PAW	policy action window
PC	personal computer
PEF	product environmental footprint
PF	performance
PR	price
R&D	research and development

RAM	random access memory
RC	Regulatory Committee
SCOP	seasonal coefficient of performance
SEER	seasonal energy efficiency ratio
SSD	solid state drive
STC	streaming client
TEC	total energy consumption
TFEU	Treaty on the Functioning of the European Union
TL	top loader (washing machine)
US	United States (of America)
WEC	World Energy Council
WLAN	wireless local area network
WTO	World Trade Organization
YR	year

Summary

Energy efficiency improvements in end-uses constitute a large potential to curb primary energy demand into a more sustainable direction. This thesis addresses some of the challenges for two types of mandatory product policy measures that tap into that potential (minimum efficiency performance standards (MEPS) and energy labels) and investigates how these measures can be made more effective and efficient.

Both MEPS and energy labels can become more ***effective*** by:

- Countries learning from each other's policies. This thesis demonstrates a method, ***mapping and benchmarking***, how to compare energy efficiency levels across countries. Three products have been benchmarked and an improvement has been shown in efficiency over time in all countries for which data was collected. The mapping of these products for the EU shows large energy efficiency potential: between 37 % and 63 %. Furthermore, the dynamic aspect of policies, i.e. the regular update of MEPS and energy labels, seems to be more important in improving efficiency than the choice of a specific policy.
  Both the Japanese Top Runner programme and the EU Ecodesign scheme contribute significantly to the energy efficiency targets of their respective jurisdictions, and both can learn from each other.
- Applying ***experience curves*** in life cycle cost (LCC) calculations. Experience curves provide an estimate for the experience ratio, the reduction in costs when cumulative production volume is doubled. Currently prices used in LCC calculation are mostly overestimated. Using experience curves provides more realistic, lower price estimates and thereby results in more stringent MEPS levels. For the EU Ecodesign scheme additional savings were estimated to be more than 140 % for laundry driers and 100 % for refrigerator-freezers.
- Using a ***top runner approach*** that allows for more stringent MEPS, regarding level and/or timing. Furthermore, the top runner approach can be used as an alternative for products where the price does not relate to the energy efficiency and therefore LCC calculations can not guide the setting of MEPS. This thesis shows that for 15 consumer electronic and information and communication products, except internal

power supplies for computers, price does not relate to the efficiency of the product if also performance and time are taken into account. For these products, the MEPS level can be set by the level of ambition of the policy, and the average price decrease of the product guides the entry into force date of the measure.

The process of preparing and adopting MEPS and energy labels can be made more ***efficient*** by:

- Using the concept of the ***policy action window*** (PAW) to make the overall process more efficient by avoiding spending time on policy measures for products that improve efficiency fast enough without measures. Since the process of preparation and adoption of product efficiency measures can easily take three years or more, policy makers should be cautious in preparing measures that have a PAW of less than three years.
- Applying a ***horizontal approach*** where in one measure MEPS are set for a single functional aspect for a large number of products. The EU measures for standby and networked standby are examples of a horizontal approach.
- Taking into account ***characteristics of the product*** allowing for better tuning the process. Products that have a lower than average technical complexity and political sensitivity could have a shorter process. A shorter process results in more savings, because measures can come into force earlier.

Obviously, this thesis can not address all challenges that product energy policy faces. Two other challenges that would require and deserve a separate study are market surveillance and the relation of product energy policy with other energy policies. The topic of market surveillance includes both the improvement of market surveillance itself and improvement of measures to enable more effective and efficient market surveillance. Regarding the relationship with other energy policies, e.g. for buildings and installations, an important question is how measures can be designed to reinforce each other.

Samenvatting

Verbetering van de energie-efficiëntie in het eindgebruik vormt een groot potentieel om de behoefte aan primaire energie in een meer duurzame richting om te buigen. Dit proefschrift bekijkt twee soorten verplichte beleidsmaatregelen voor producten die dat potentieel realiseren (minimum efficiëntie prestatie eisen (MEPS) en energielabels) en onderzoekt hoe deze maatregelen effectiever en efficiënter gemaakt kunnen worden.

Zowel MEPS als energielabels kunnen ***effectiever*** worden:

- Doordat landen kunnen leren van elkaars beleid. Dit proefschrift laat een methode zien, ***mapping en benchmarking***, om energie-efficiëntie van producten tussen landen met elkaar te vergelijken. Drie producten (koelvriescombi's, wasmachines en wasdrogers) zijn gebenchmarked: de energie-efficiëntie van deze producten verbetert in de tijd in alle landen waarvoor gegevens zijn verzameld. De mapping van deze producten voor de EU toont een groot energie-efficiëntiepotentieel: tussen 37 en 63 %. Verder lijkt het dynamisch aspect van het beleid, dat wil zeggen het regelmatig herzien van MEPS en energielabels, belangrijker te zijn voor de verbetering van de efficiëntie dan de keuze van een specifiek instrument.
  Zowel het Japanse Top Runner-programma als de EU Ecodesign richtlijn dragen aanzienlijk bij aan de doelstellingen voor energie-efficiëntie van Japan respectievelijk de EU, en beide kunnen van elkaar leren.
- Door ***leercurven*** in levenscycluskostenberekeningen (life cycle costs: LCC) toe te passen. Leercurven leveren een schatting voor het leerpercentage, de vermindering van de kosten wanneer het cumulatieve productievolume verdubbeld is. Op dit moment worden de prijzen van producten die in LCC berekeningen gebruikt worden meestal overschat. Het gebruik van leercurven leidt tot meer realistische, lagere, schattingen van prijzen en daarmee tot strengere MEPS-niveaus. Voor de EU Ecodesign richtlijn worden de extra besparingen voor wasdrogers en koelvriescombi's op meer dan het dubbele geschat.
- Door gebruik te maken van een ***top runner aanpak*** die voorziet in strengere MEPS, met betrekking tot niveau en/of timing. De top runner benadering kan ook worden gebruikt als alternatief voor producten waar de prijs geen relatie heeft met de

energie-efficiëntie en waarbij LCC berekeningen niet bruikbaar zijn als leidraad voor het opstellen van MEPS. Dit proefschrift laat zien dat voor 15 consumentenelektronica en informatie- en communicatietechnologie producten, met uitzondering van interne voedingen voor computers, de prijs geen relatie heeft met de efficiëntie van het product als ook prestaties en tijd in aanmerking worden genomen. Voor deze producten kan het MEPS-niveau worden vastgesteld op basis van het ambitieniveau van het beleid. De daling van de gemiddelde prijs van het product geeft aan wanneer de eisen in werking kunnen treden.

Het proces van voorbereiding en vaststellen van MEPS en energielabels kan ***efficiënter*** gemaakt worden door:

- Geen tijd te besteden aan beleidsmaatregelen voor producten die zonder beleidsmaatregelen snel genoeg efficiënter worden. Het concept van het ***beleidsactievenster*** (policy action window; PAW) geeft een indicatie hoe lang het duurt voordat vrijwel alle producten op de markt efficiënter geworden zijn. Aangezien het proces van voorbereiding en vaststellen van productefficiëntiemaatregelen gemakkelijk drie jaar of meer kan duren, moeten beleidsmakers terughoudend zijn om maatregelen voor te bereiden voor producten die een PAW van minder dan drie jaar hebben.
- Een ***horizontale benadering*** toe te passen. Hierbij wordt in een maatregel voor een groot aantal producten een MEPS voor een enkel functioneel aspect vastgelegd. De EU ecodesign verordeningen voor stand-by en netwerk stand-by zijn voorbeelden van een horizontale benadering.
- Rekening te houden met de ***kenmerken van het product*** en daarop het proces af te stemmen. Voor producten die een lager dan gemiddelde technische complexiteit en politieke gevoeligheid hebben, kan het proces korter duren. Een korter voorbereidingsproces levert meer besparingen op, omdat maatregelen eerder van kracht kunnen worden.

Dit proefschrift kan uiteraard niet ingaan op alle uitdagingen waarmee het product-energiebeleid wordt geconfronteerd. Twee andere uitdagingen die een aparte studie vereisen en verdienen, zijn het markttoezicht en de relatie van het product-energiebeleid met ander energiebeleid. Het onderwerp van het markttoezicht omvat zowel de verbetering van het markttoezicht zelf als verbeteringen van de maatregelen om meer effectief en efficiënt markttoezicht mogelijk te maken. Met betrekking tot de relatie met ander energiebeleid, bijvoorbeeld voor gebouwen en installaties, is een belangrijke vraag hoe maatregelen in diverse beleidsterreinen kunnen worden ontworpen zodat deze elkaar versterken.

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Curriculum vitae

Hans-Paul Siderius was born on September 14, 1962 in Bunschoten. In 1980 he received his Atheneum B certificate at the Marnix College in Ede. In 1986 he finished his study at the Technical University in Eindhoven with a master (cum laude) in Electrical Engineering. He worked at the technical department of SWOKA, Institute for Consumer Research, in The Hague from 1986 till 1995. From 1992 he also studied Business Administration at the Open University in Heerlen and finished his master in 1997. From 1995 till 2000 he worked as senior engineer at Van Holsteijn en Kemna in Delft. In 2000 he started working at Novem, one of the predecessors of SenterNovem, NL Agency and his current employer the Netherlands Enterprise Agency. From 2004 he also studied Dutch Law at the Open University and finished his master in 2008. He was the first chair of the IEA implementing agreement 4E (Efficient Electrical End-use Equipment) in the period 2009-2012. He is representing the Netherlands in the Ecodesign Regulatory Committee since 2005. Since 1984 he has held various voluntary offices in the Protestant Church in the Netherlands, in Eindhoven, The Hague and Utrecht. At the end of 2010 he started working on this thesis.