Energy Efficient
End-Use Equipment
International Energy Agency

Progressing Energy Efficiency Policies for Systems

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Product Energy Efficiency Trends -
A project of the Energy Efficient End-use Equipment TCP

Technology Collaboration Programme
by iea

About 4E

The Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E TCP), has been supporting governments to co-ordinate effective energy efficiency policies since 2008.

Fourteen countries and one region have joined together under the 4E TCP platform to exchange technical and policy information focused on increasing the production and trade in efficient end-use equipment. However, the 4E TCP is more than a forum for sharing information: it pools resources and expertise on a wide a range of projects designed to meet the policy needs of participating governments. Members of 4E find this an efficient use of scarce funds, which results in outcomes that are far more comprehensive and authoritative than can be achieved by individual jurisdictions.

The 4E TCP is established under the auspices of the International Energy Agency (IEA) as a functionally and legally autonomous body.

Current Members of 4E TCP are: Australia, Austria, Canada, China, Denmark, European Commission, France, Japan, Korea, Netherlands, New Zealand, Switzerland, Sweden, UK and USA.

Further information on the 4E TCP is available from: www.iea–4e.org

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1 Introduction

Energy-using systems represent a largely untapped potential to extend the significant energy and greenhouse gas savings already achieved by energy efficiency regulations on individual products (product policies)[1].

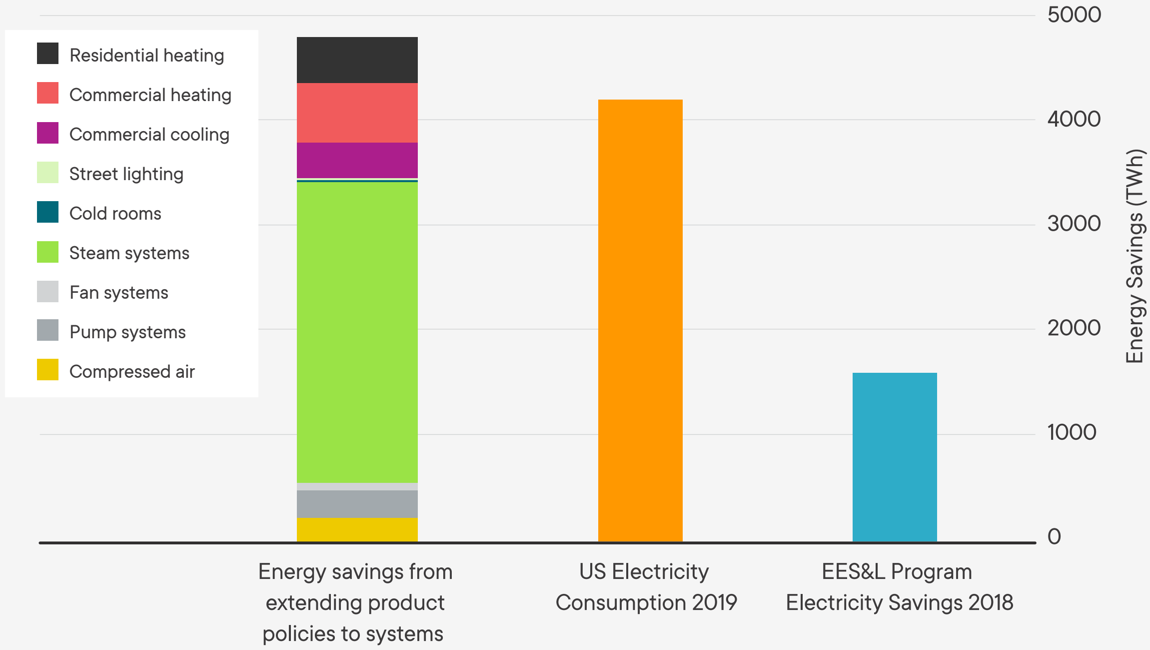
This report summarises the results of investigations that have been conducted by the 4E TCP over the previous four years into the practicality of energy efficiency regulatory policies for energy-using systems.

These investigations are ongoing and the 4E TCP welcomes further discussion and interaction on this topic.

2 Savings potential

Extending product policies to cover relevant energy-using systems has the potential to reduce annual global energy consumption by 9% (17,000 PJ, 4,780 TWh). This is larger than the total annual use of electricity in the Unites States in 2021. It is also more than three times the electricity savings generated by the nine most successful national standards and labelling programmes for individual products[2].

Figure 1: Estimates of energy savings if product policies were extended to cover energy using systems



This estimate considers the nine energy-using systems used extensively in the industrial, commercial and residential sectors, as listed in Table 1. Together they consume more than half the total fossil fuel and electrical energy consumption within these sectors. Other systems, such as materials handling and processing, multimedia and ICT systems, are not included at this stage due to lack of information but are likely to have potential for significant additional savings.

1 See *IEA 4E Achievements of Energy Efficiency Appliance and Equipment Standards and Labelling Programmes: A Global Assessment in 2021* https://www.iea-4e.org/wp-content/uploads/2021/11/AchievementsofEnergyEfficiencyApplianceandEquipmentStandardsand-LabellingProgrammes.pdf

2 See ibid

Our estimate represents the savings potential due to the implementation of product policies, such as minimum energy performance standards (MEPS), and is therefore less than the full technical potential[3]. For example, the correct sizing of a system is typically not something that can be guaranteed by MEPS.

The estimated energy savings relevant to product policies are largely from improvements to the efficiency of individual parts[4] (components), overall system design, maintenance and matching energy use to demand via better controls. We have assumed that better design, assembly and control systems required by product policy would enable and encourage better maintenance. The quantity of energy savings from better system control and maintenance are often two to three times larger than those from parts alone. Over half of these estimated savings are from steam systems alone, but excluding this still results in savings of 6,890 PJ (1,910 TWh) annually.

Table 1: Summary of annual savings estimates for different systems, worldwide

System	Energy consumption		Estimated policy savings %	Total savings	
	PJ	TWh		PJ	TWh
Compressed air	2,540	700	30%	760	210
Pump systems	3,880	1,080	24%	930	260
Fan systems	2,580	720	10%	260	70
Steam systems	43,000	11,940	24%	10,320	2,870
Cold rooms	180	50	20%	40	10
Street lighting	510	140	23%	120	30
Commercial cooling	4,930	1,370	24%	1,170	330
Commercial heating	12,860	3,570	16%	2,020	560
Residential heating	31,810	8,830	5%	1,590	440
All systems	**102,280**	**28,410**	**17%**	**17,210**	**4,780**
All systems (excl steam)	**59,280**	**16,470**	**12%**	**6,890**	**1,910**

3 Technical potential means the total energy efficiency potential without any economic or market constraints
4 See following section for relevant definitions

3 Defining a system for energy efficiency regulation

For our purposes, we define a system as 'a functional unit that consists of two or more physical parts that need to be assembled at the location where the system is used'.

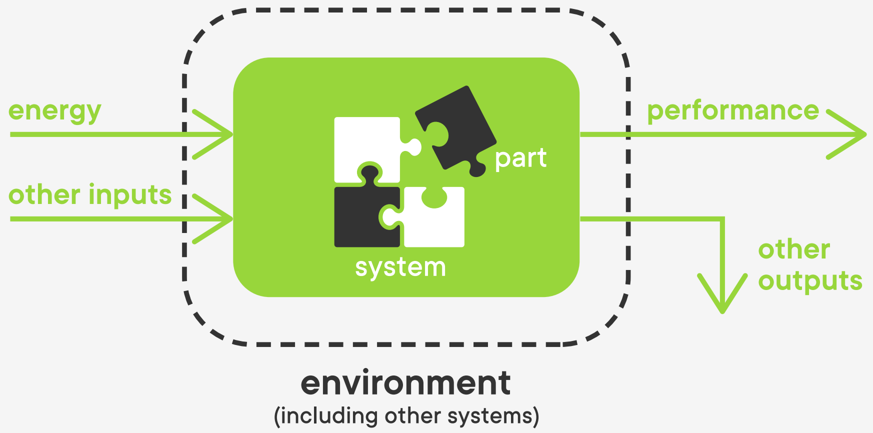
Where:

The **functional unit** draws a boundary between the system and the environment or other systems.

A **part** is a single, identifiable piece that contributes to the function of the system and which needs to be assembled at the location. For example, a hydraulic pump, an electric motor, a variable speed drive and water pipes are **parts** of a water pump system.

A system is **assembled** by connecting the parts together on location and is typically undertaken by a professional actor. Systems and products must also be installed, i.e. connected to another system in the environment such as an energy grid or a piping system.

Figure 2: System aspects



In our definition, a system exists and interacts within an environment where other systems exist. It uses energy, and often other inputs, and it delivers a certain performance (functionality). At the same time it delivers other outputs to the environment such as (waste) heat and emissions.

The external environment imposes conditions such as ambient temperature, humidity, luminance level, or conversely systems may require certain environmental conditions in order to operate.

Other features of systems include their ability to be extended by adding new parts to increase capacity or functionality.

The ability of a system to function properly when some or all the parts of a system are provided by different manufacturers is also an important feature.

Size and weight are not distinguishing characteristics of products and systems. For example, transformers can be large and heavy products, whereas a lighting system can be relatively small and light.

While systems are usually able to be customized, customization is not unique to systems and therefore is not suitable for defining a system. For example, products such as computers are often built-to-order and the performance of standard products can be modified by software.

4 Classifying systems for regulation

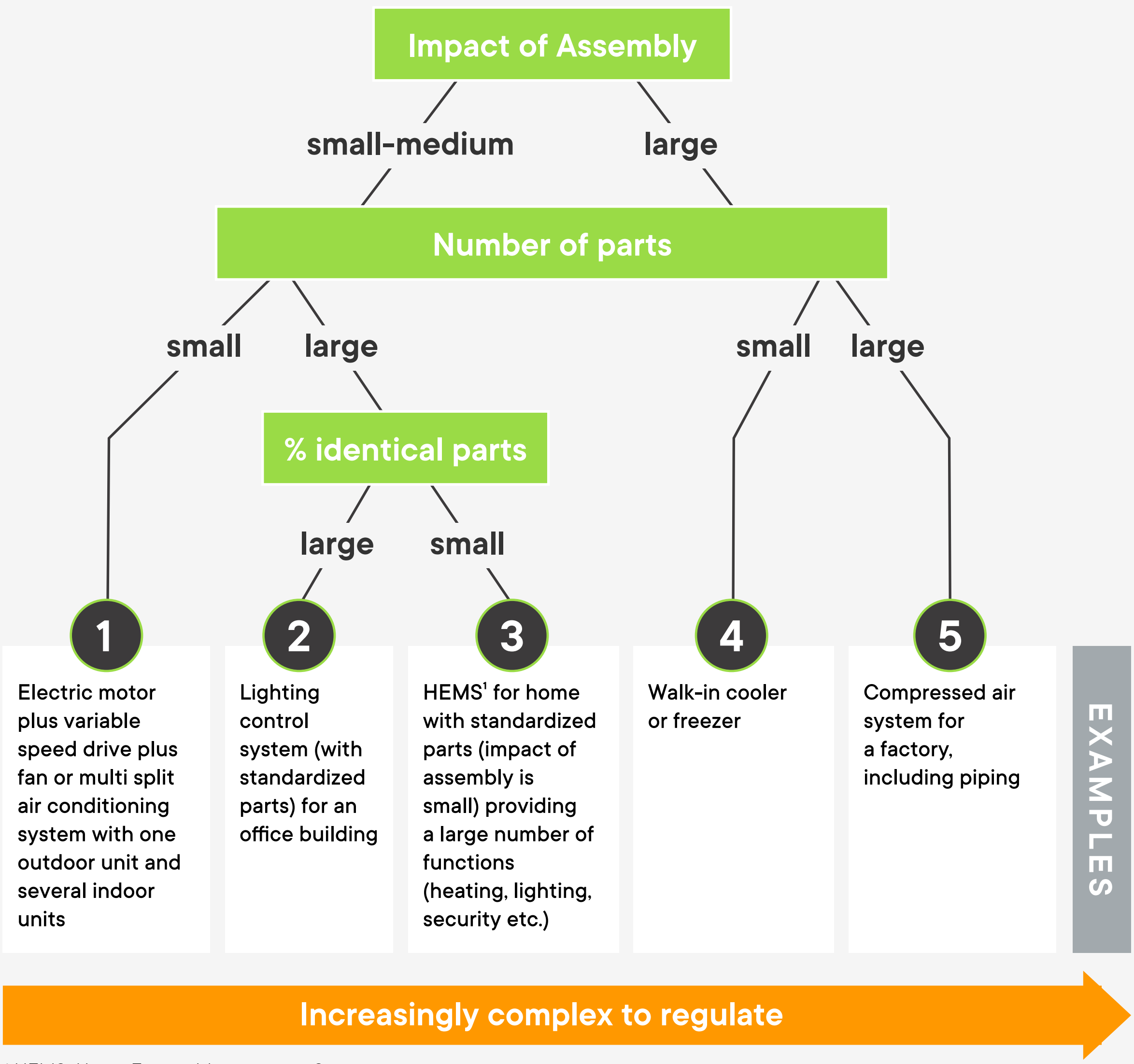
The following three factors appear to be highly influential in determining the complexity of potential system regulations:

- The number of parts within a system
- The extent to which these parts are identical
- The impact of the assembly on the performance and the energy consumption of the system.

This can be further simplified if it is assumed that where the impact of the assembly is large then the percentage of identical parts will not be large; and conversely if the number of parts is small then they will not be identical.

As a result, we suggest using the following classification tree to distinguish between different types of systems for regulatory purposes.

Figure 3: Classification tree



1 HEMS=Home Energy Management System

5 Regulating system efficiency policies

Systems can vary greatly and the conditions in which they operate can also vary to a large degree. These factors pose particular challenges for energy efficiency regulations, which are discussed further below, together with some potential solutions.

Regulatory powers

To regulate systems, relevant authorities need to have powers to adopt, execute and enforce appropriate measures. Relevant issues therefore include:

- Whether the scope of existing regulatory powers covers systems.
- Whether there are jurisdictional limitations arising from the assembly of systems in a different location from the place of supply or sale.
- If market surveillance authorities have the power to enforce cooperation in case of testing or assessing a system on location.

Box 1: Example of definitions within the EU Ecodesign Directive related to systems

The essence of the EU Ecodesign Directive is setting ecodesign requirements for products for which the manufacturer is responsible regarding conformity. An energy related product is defined as any good that has an impact on energy consumption during use.

The Directive defines two moments at which this responsibility materializes:

- Placing on the market
- Putting into service

Related to the definitions proposed in this document: *placing on the market* fits the (equipment) products that are produced in a factory, sold and installed at the end-user, whereas *putting into service* fits the (equipment) systems of which the parts are assembled (and installed) on location at the end-user.

This means that the Ecodesign Directive, although only defining "products", covers both products and systems (as defined in this document). In the framework of the Ecodesign Directive a system can be defined as a product that is not placed on the market but only put into service. The individual parts of a system may have been placed on the market, but not the system as an assembled whole.

Further note that the definition of a manufacturer is a "legal" one: the legal person that placed the product on the EU market or puts it into service is called the manufacturer of the product, regardless whether "technically" it is the manufacturer, retailer or installer.

Content of regulations for systems

Energy efficiency regulations need to define at least the following elements:

- The ***scope*** which identifies those products or systems that are included and excluded.
- The ***addressees*** of the regulation
- The energy efficiency ***metric(s)*** and ***requirements***
- The ***performance*** assessment methods including testing or alternatives.

Additionally, the development of regulations needs to work hand in hand with appropriate methods for ***verification and enforcement.***

Issues relating to these topics are discussed further below.

Scope

The technical scope of regulations is typically defined in relation to the main function(s) and/or the characteristics of the product or system. Focusing on the function(s) enables a "technology neutral" scope[5], which allows either products or systems providing the designated function(s) to be covered. This is desirable to create a level playing field and avoid loopholes where both products and systems can provide the same function scope, e.g. moving air or pumping liquid. Defining the system boundaries is also an important part of defining the scope for a regulation.

Addressees

For systems there are likely to be different types of addressees: the manufacturer of the parts, the company that offers the system to a customer, the customer that specifies the system or the company that assembles (and installs) the system.

Clearly specifying a single addressee for each and every requirement within regulations helps to create legal certainty.

Efficiency metric and requirements

Efficiency metrics relates output (performance) to input (energy). However, for systems, the performance depends on the assembly, the design and the location where it is installed and used. Regulatory requirements may therefore need to account for variations in these conditions. For example, in determining the efficiency of an electric pump, energy consumption may be measured under different loads and the overall efficiency calculated using a weighting reflective of real usage patterns. Given the potential variations in conditions, a single requirement for all systems in scope may not be feasible.

While setting a requirement for the system could make requirements for individual parts superfluous, in practice this is seldom the case. This is particularly true when parts used in regulated systems are sold as standalone products as it is not feasible to determine the final application of these parts. In addition, when the performance of a system is derived from modelling and this relies upon the on the performance of the parts as input data, the use of the regulated performance requirements for the parts helps to improve accuracy.

Finally, in setting the requirements for individual parts, care should be taken to ensure that these do not hinder achieving system level energy efficiency requirements.

5 An example is a regulation for light sources that would define the scope as all light sources that provide visible, white light. This would include incandescent, fluorescent and LED light sources.

Performance assessment methods including testing

Some of the key options for assessing system efficiency and performance are described in Table 1. These may be used individually or in combination.

Table 2: Options for system performance assessment

Approach	Description
Black box	The black box approach does not care what is in the box (the system); the relevant inputs and outputs are assessed. This is the product testing approach applied to a system.
Modular	The modular approach measures the performance and energy consumption of component **parts**. The overall system energy consumption or efficiency is calculated using a formula to combine the measured results. This approach can resemble the modelling approach (see below), especially when a complex formula is used. The difference is that in the modelling approach usage conditions and/or operational range are included *in the model*, whereas in the modular approach these elements are assumed to be taken into account in the measurement of the parts.
Procedural	This approach focuses on the assembly and installation of the system. It could include rules for sizing the system and the parts and how they should be assembled and installed. Each step of the sizing, assembly and installation are required to be documented and checked. In principle no measurements of parts are needed, although information about each of the parts are likely to be needed. This approach resembles quality management systems. The assumption is that if the right procedure is followed then the efficient functioning of the system is guaranteed.
Statistical	This approach uses on-site measurements of energy consumption, performance, usage and operational conditions to determine relevant values used in modelling or test procedures. This helps to increase the accuracy of the conditions used by these other approaches. In addition, this approach can be used to monitor installations, or for certification to show that a system performs as specified/calculated.
Modelling	The modelling approach comes in two main variants. The first uses a mathematical model of (parts of) the system to calculate the performance and energy consumption or efficiency based on design parameters of the parts. The second uses a scale model of the (parts of the) system on which measurements are done after which the results are scaled up to give results for the system. The design parameters of parts may be checked independently.

Verification and enforcement

There are three levels of verification (including any combination of them) relevant to systems regulation:

- **System level:** the system is tested once assembled. Modelling can be used to cover the full extent of the “operational” range of the system.
- **Part level:** all parts of the system are tested; results for the system can be derived via a model or simulation.
- **Assembly:** the quality of the assembly is checked.

Verification on the part level is most useful where the number of parts is large and identical.

Where the assembly and installation has a significant impact on the performance of the system, verification should focus on the (quality of the) assembly and the assembler should be one of the addressee(s), particularly when one or more parts are already regulated. This could go as far as requiring assemblers to have a quality management system. Another option would be to regulate standardization of the assembly with the aim to reduce the impact of the assembly on the efficiency. This could also reduce assembly time and costs.

Where the assembly has a smaller impact, the addressee(s) can be the manufacturer of the system or another company that offers the system to a customer. This could cover the variations of systems so long as all of these are proven to comply with the regulation.

There are some challenges with verification including:

- Although the documentation of a system can be verified in the same way as for a product, a system can only be tested when it is assembled and installed on location.
- The location where the system is tested can in some cases be a laboratory, although this becomes more difficult for physically large systems.
- When testing at a location where the system is actually used, the market surveillance authorities need to have access to that location.
- It is difficult to test a system that is already in operation, since is likely to disturb essential processes at the location (e.g. in a factory or commercial site); so systems on location have to be tested before starting operation. This would require that the market surveillance authorities know when a system is assembled.
- A verification method that requires cooperation of an addressee, may also be difficult to enforce especially if the cooperation itself cannot be enforced.

Based on these considerations, we can begin to distinguish different kinds of systems, identify their major attributes and consider some of the key elements required for regulations. Table 3 shows how this is applied to three common systems.

Table 3: Attributes relevant to regulating three case studies

Case Study	Compressed Air System	Lighting Control System	Energy monitoring & management system (EMMS)
Major parts	• Compressor(s) • Air cooler/ Air storage tank • Filter(s)/Dryer/Condensate trap, Lubricator • Distribution system • Maintenance units • Ancillary devices/units	• Lamp and control gear • Luminaire • Sensors • Non-lighting functions • Control system	• Smart meters, gateways (Transmitter) • Sensors and actuators • Smart plugs (connected thermostats) • Display and home assistants • (Cloud) platforms, web-based energy services
Number of parts	Large	Large	Medium - Large
Percentage of identical parts	Small	Large	Small - Medium
Percentage of standardized parts	Small	Large	Large
Impact of parts on energy consumption	Mixed	Mixed	Mixed
Impact of assembly on energy consumption or performance	Large	Small	Medium - Large
Impact of location	Small	Medium	Medium – Large
Number of actors involved	2-5	2-5	>5
Performance measure	• No overall performance metric defined • Level of the pressure losses over a certain time without any usage (standby) • MEPS for compressor as part of the system	• Energy use in kWh/y.m² • Requirement differentiated towards different functions	• Energy performance class of each control function (CF) • Single CF scores combined into performance Class for the complete system
Addressees	• Manufacturers of the parts. • Assemblers & installers of the system • The owner/purchaser of the system	• The designer of the system • The manufacturers of the parts, especially the control system	• EMMS and platform developers • Installers and building managers • Energy utilities.

6 Approaches for assessing the performance of different systems

Table 4 maps the different options for the assessment of system performance against the main variables that we find in systems, to provide an indication of how these can be applied.

Table 4: Mapping assessment approaches to classification and conditions

Approach	Impact of assembly		Number of parts		% Identical parts		Variation in conditions	
	small	large	small	large	small	large	small	large
Black box								
Modular								
Procedural								
Statistical								
Modelling								

Key:
- Most suitable approach
- Element not relevant for the approach
- Approach can only be applied in once the system is in use

This suggests that:

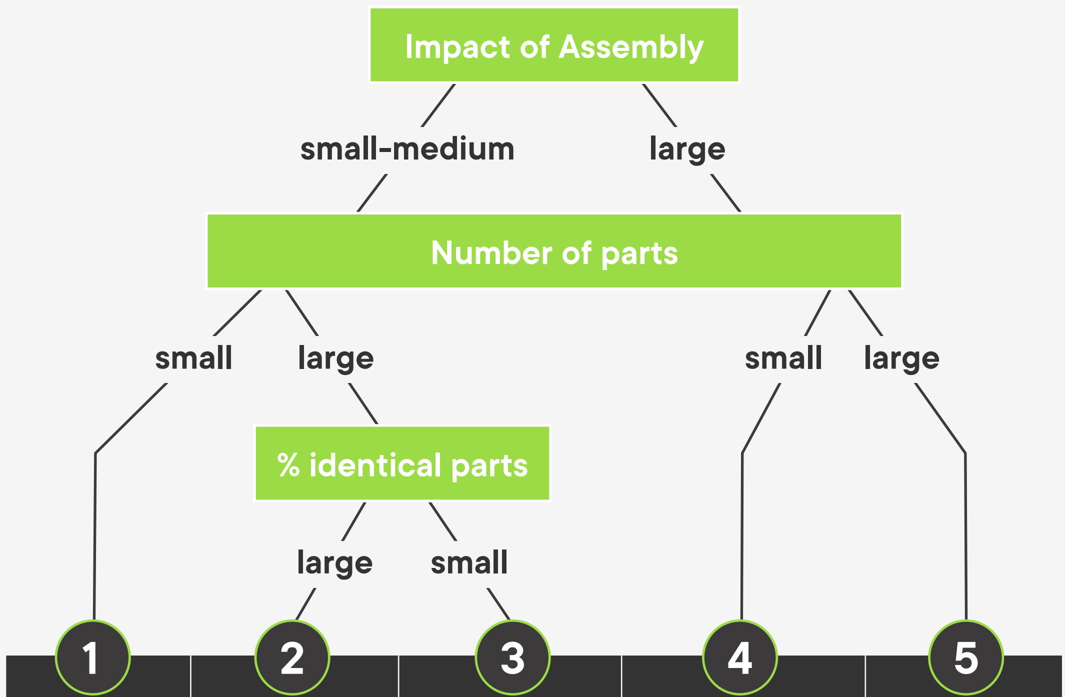
- Where the impact of assembly is large, the procedural approach is most appropriate.
- Where the impact of assembly is small, the modular and modelling approaches are likely to be most useful.
- Where the system consists of a medium to large number of different parts and therefore the number of system variants is significant, then the regulation should include modelling[6].
- Where the proportion of identical parts is large, or where the parts have a significant impact on energy consumption, these parts can be tested (black box approach) and regulated

6 If modelling is allowed, the regulation should either include the calculation or simulation model or indicate how third-party calculations or simulations will be verified.

7 Mapping systems and regulatory solutions

Combining the above findings, Figure 4 below provides guidance on the appropriate regulatory elements for each type of system.

Figure 4: Mapping systems and regulatory solutions



	1	2	3	4	5
Scope and addressees	Manufacturers of (parts of) the system	Manufacturers of the parts	• Manufacturers of the identical and/or critical[7] parts of the system • Assemblers & installers of the system	• Manufacturers of the parts • Assemblers & installers of the system	• Assemblers & installers of the system • The owner/ purchaser of the system
Efficiency metric and requirements	Efficiency of the parts and the system	Efficiency of the parts	• Efficiency of the (identical/critical) parts • Efficiency of the system as assembled and installed	• Efficiency of the parts • Quality (control) of the assembly & installation	Quality (control) of the assembly & installation
Verification and test methods	Measurements on the parts of the system; modelling to provide results for the system (in a variety of usage conditions)	Measurements on the parts	• Measurements on the (identical/ critical) parts • Modelling to calculate system efficiency as assembled and installed	• Measurements on the parts • Check on the quality (control) of the assembly & installation	Check on the quality (control) of the assembly & installation

7 critical with regard to energy consumption of the system

Other energy efficiency issues

We note that the following issues may influence the energy consumption of systems but may not be covered by regulatory approaches:

- Specification of the system: an incorrectly specified (e.g. oversized) system is likely to use more energy.
- Commissioning: this could be seen as part of the installation, but requires separate attention, e.g. for larger systems and for systems that are closely coupled with other systems.
- Operation and maintenance: incorrect operation or improper maintenance can significantly increase energy consumption of a system. Assessing and correcting this is part of a quality control or energy management scheme over the lifetime of the system.
- Software can have a major influence on energy consumption.
- Adaption/change of the system during its lifetime, including software updates after installation. In some cases this might constitute a new system that may have to prove compliance with current regulations, depending on the regulatory framework[8].

8 Conclusions

The expansion of current product policies to regulate energy-using systems has the potential to reduce energy consumption by the equivalent of nearly 5,000TWh per annum, several times the savings currently realized through these policies.

While including energy using systems within product policies poses considerable challenges, the scale of opportunity justifies considerable further investigation.

This report represents a summary of the work undertaken by 4E over several years, and since this is ongoing, this report should be considered a 'work in progress'.

Particular features of energy-using systems that are challenging include the large range of conditions in which some systems operate and how to verify the performance of systems installed in premises.

However, based on a new way of classifying different types of systems illustrated in this report, not all systems are the same. As a result, it is likely that one single regulatory approach will not suit all, and we have also show which different approaches may best be applied to each system type.

This framework is helpful in suggesting which types of systems will be more amenable to product policies, and therefore should form the focus of further exploration. These efforts will include the investigation of which regulatory and market surveillance powers are appropriate in order to effectively pursue regulating energy-using systems.

8 See: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C:2022:247:FULL&from=EN