European Commission

Review study on Tumble driers

Draft interim report

March 2018

The information and views set out in this study are those of the author(s) and do not necessarily reflect the official opinion of the European Commission

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I. Summary

This is the interim report for the review of Ecodesign Regulation 932/2012 and Energy Labelling Regulation 392/2012 for tumble driers. The study follows the structure of the MEErP methodology of which the draft interim report concerns tasks 1 to 4 and is intended to create the basis for discussion at the first stakeholder meeting.

Scope

The overall scope of this review study is proposed to remain the same as the scope of the ecodesign and energy labelling Regulations[1] for tumble driers. The driers can be classified either based on the heating technology (gas, heat element or heat pump) or on the mechanism to remove the clothes' moisture (i.e. drier technology, which can be vented or condensing).

Gas-fired technologies represent a small share of the market which is expected to vanish by 2030, and according to information from industry, no major improvements are expected to happen in the future. Limited data available on energy efficiency and consumption confirm this, but it shall be discussed further at the stakeholders meeting. Therefore, it is questionable whether these should remain in scope of the Regulations. An analysis will be made to quantify potential savings to justify whether they shall remain in scope.

Review of legislation and standards

A review of relevant legislation which came into force after the preparatory study of laundry driers in 2009[2] is presented in Table i. This legislation is relevant because it regulates energy efficiency and/or consumption of different aspects and components of tumble driers. The requirements in these Regulations shall be considered when developing policy options to avoid double counting.

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[1] Commission Regulation (EU) No 932/2012, available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0932&from=EN and Commission Delegated Regulation (EU) No 392/2012, available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0392&from=EN

[2] Preparatory study of Ecodesign for Laundry Dryers, PriceWaterhouseCoopers, 2009.

Table i: Summary of legislations relevant to ecodesign Regulation 932/2012 and energy label Regulation 392/2012 of tumble driers

Relevant for	Name	Relevance to current review study	Aim of Regulation	Valid from	Specific relevant requirements Regulation
Ecodesign	Commission Regulation (EU) No 2016/2282	Tolerances for verification procedures in Ecodesign Regulation	Amend numerous Ecodesign Regulations (incl. tumble driers) with regard to the use of verification tolerances	2016	The verification procedure in Annex III of Regulation 932/2012 is replaced by procedure in Annex XIII of Regulation 2016/2282
	Commission Regulation (EC) No 640/2009	Ecodesign efficiency requirements that may be applicable for the electric motors driving the fans and the drum in tumble driers	Set ecodesign requirements for electric motors (under revision, incl. scope of the requirements)	2009	Minimum efficiencies for electric motors related to rated power consumption
	Commission Regulation (EU) No 1275/2008 (including four amendments)	Ecodesign energy requirements for off mode and networked standby as well as power management function	Set ecodesign requirements for standby, networked standby and off modes including power management	2013	Power consumption requirements: Off mode ⩽0.5W and Networked standby ⩽ 3W Equipment shall offer a power management function switching equipment after the shortest period of time into off-mode
Energy labelling	Commission Delegated Regulation (EU) No 2017/254	Tolerances for verification procedures in energy labelling Regulation	Amend numerous energy label Regulations (incl. tumble driers) with regard to the use of verification tolerances	2017	The verification procedure in Annex V of Regulation 392/2012 is replaced by procedure in Annex VI of Regulation 2017/254
	Commission Regulation (EU) No 518/2014	Availability of tumble driers energy label and fiche online	Amend numerous energy label Regulations (incl. tumble driers) with regard to labelling on the internet	2014	Articles 3 and 4 of Regulation 392/2012 are amended according to article 6 of Regulation 518/2014
	EU Regulation 2017/1369	Setting a new framework for energy labelling including rescaling of the energy label	Replace Energy labelling Directive 2010/30/EU	2017	New rules for rescaling energy classes and registration of product database, amongst others

A summary of the relevant standards to the review of ecodesign and energy labelling Regulations is presented in Table ii.

Table ii: Summary of relevant standards for ecodesign and energy labelling Regulations

Name	Aim of standard	Valid from	Replacing / Expanding standard
EN 61121:2013	Methods for measuring the performance of electric mains TDs	2013	Supersedes EN 61121:2005
EN 1458-2:2012	Methods for measuring performance for gas-fired TDs	2012	Supersedes EN 1458-2:2001
EN 60704-2-6:2012 (IEC 60704-2-6:2012)	Methods for determining airborne acoustical noises for TDs	2012	No
EN 50564:2011 (IEC 62301-1:2011)	Methods for measuring energy consumption in standby modes (Both electric and gas fired)	2011	No
EN 1458-1: 2012	Safety requirements for gas fired tumble driers	2012	No
EN 60335-1:2012+A11:2014 (IEC 60335-1:2010+A1:2013+A2:2016)	General safety requirements for electric connections in appliances.	2012 /2014	No
ISO 11469:2016	General identification and marking of plastic products	2016	No
EN ISO 1043-2:2011	Defines abbreviated terms and symbols for basic polymers used in components	2011	No
IEC TR 62635:2012	Guidelines for end-of-life information provided by manufactures/recyclers.	2012	No
EN 50625-1:2014	Implementation and effectiveness of WEEE	2014	No
EN 62321	Test methods for determining levels of certain substances in electrotechnical products		No
EN 50581:2012	Evaluation of electrical and electronic products regarding hazardous substances.	2012	No
IEC 62430:2009	ECD for electrical systems	2009	No

Market analysis

Tumble driers market data were purchased for the review study, which included sales data for the years 2006-2016. From the sales and expected lifetimes, the stock was calculated. The sales and stock numbers for the entire tumble drier market in scope of this study, is seen in Figure i. The total sales increased on average 1.6% per year from 2013 to 2016 according to purchased data[3], but it is predicted that the market will stabilise with a slower decrease towards 0% per year in 2030[4].

[3] Provided by GfK in 2018
[4] Assumption presented to APPLiA in Brussels, 21st of December 2017. No comments were provided to this assumption.

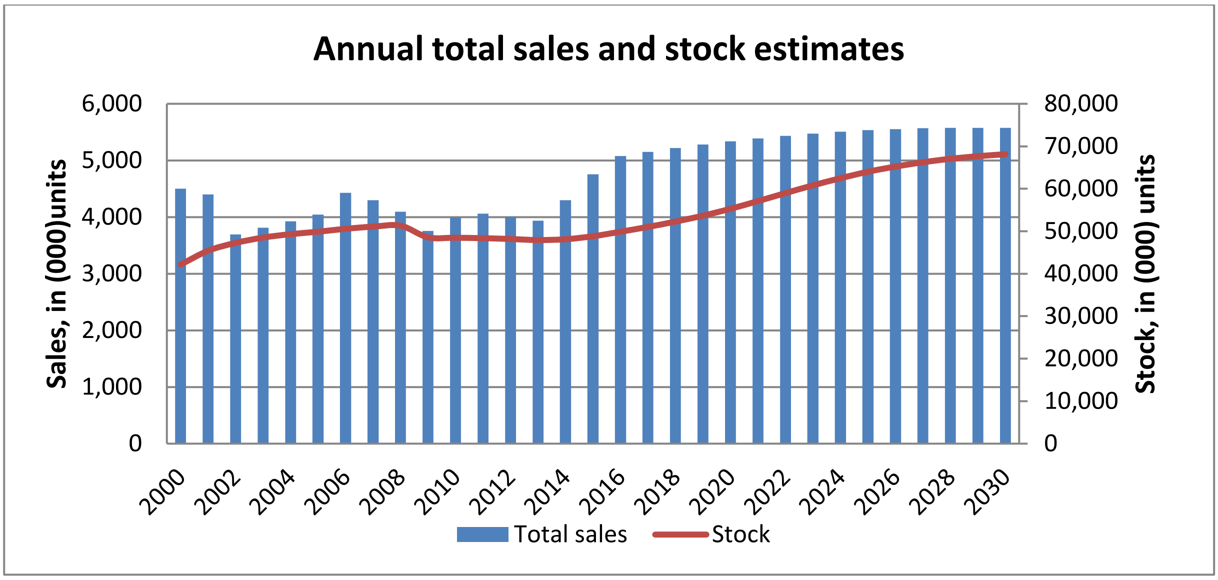

Figure i: Annual sales and stock of tumble driers (total of all types)

The sales for the different tumble driers types included in the scope are shown in Table iii. The sales data is a mix of purchased data and data from the preparatory study.

Table iii: Derived tumble drier sales from 1990 to 2030

Sales, million units		1990	1995	2000	2005	2010	2015	2020	2025	2030
Con-denser	Heat pump	-	-	-	-	0.34	2.22	3.05	3.60	4.46
	Heat element	3.55	3.55	3.44	2.38	2.54	1.78	1.68	1.55	1.11
Air-vented	Heat element	0.14	0.14	1.06	1.66	1.11	0.75	0.59	0.39	-
	Gas-fired	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-
Total		**3.70**	**3.70**	**4.50**	**4.04**	**3.99**	**4.76**	**5.34**	**5.53**	**5.57**

The total stock is split between the different tumble driers types as shown in Table iv.

Table iv: Stock of tumble driers from 2000 to 2030

Stock, million units		2000	2005	2010	2015	2020	2025	2030
Condenser	Heat pump	0.00	0.00	0.44	7.27	21.18	34.89	44.61
	Heat element	37.97	38.19	31.28	26.44	23.35	21.37	18.73
Air-vented	Heat element	4.17	11.67	16.73	15.09	10.62	7.59	4.70
	Gas-fired	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Total		**42.15**	**49.89**	**48.47**	**48.82**	**55.28**	**64.00**	**68.13**

The overall increase in sales since 2010 has been dominated by heat pump tumble driers, while all other technologies have decreased in sales numbers. The gas drier sales fluctuate, but since they make up only 0.2% of total sales, this has no influence on the total market. Both the air-vented and heat element condenser driers have decreased by roughly 1 million units in sales over the last 10 years, the air-vented from 1.7 to 0.7 million units and the heat element condenser from 2.7 to 1.7 million units. In the same period the heat pump condenser sales have increased from less than 100 thousand unit to 2.6 million units. With the total number of households in EU of 220 million in 2016, only 23% of EU households have a tumble drier.

The energy class distribution of tumble driers on the market has evolved since 2013 (see Figure ii, Figure iii and Figure iv), one year after the Energy Labelling Regulation came into force. Heat pump condenser driers present the largest shift and the most efficient driers. The energy class distribution for has remained more constant, although air-vented are more stagnant than condenser driers.

Data were not available for gas-fired tumble driers, but based on information from GfK, it was possible to track from a desktop research three of the models on the EU market which have 63% of the market share. Two of these three models (covering 61% of the market) feature an A+ energy class and the other features a C energy class. Gas-fired air-vented driers on the market are thus able to reach a higher energy class than the heating element air-vented drier. This might be due to differences in the energy efficiency calculation methods between electric operated and gas-fired tumble driers.

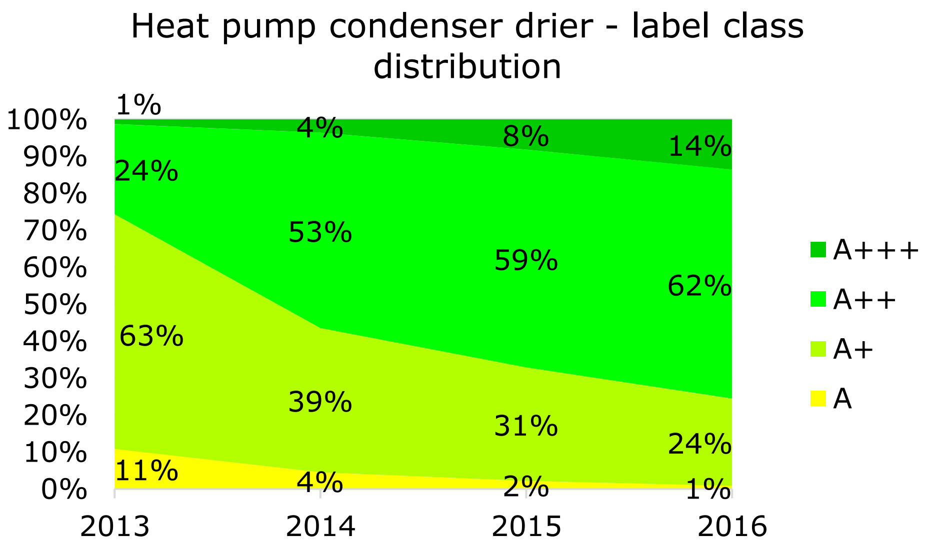

Figure ii: Energy class distribution and development for heat pump tumble driers

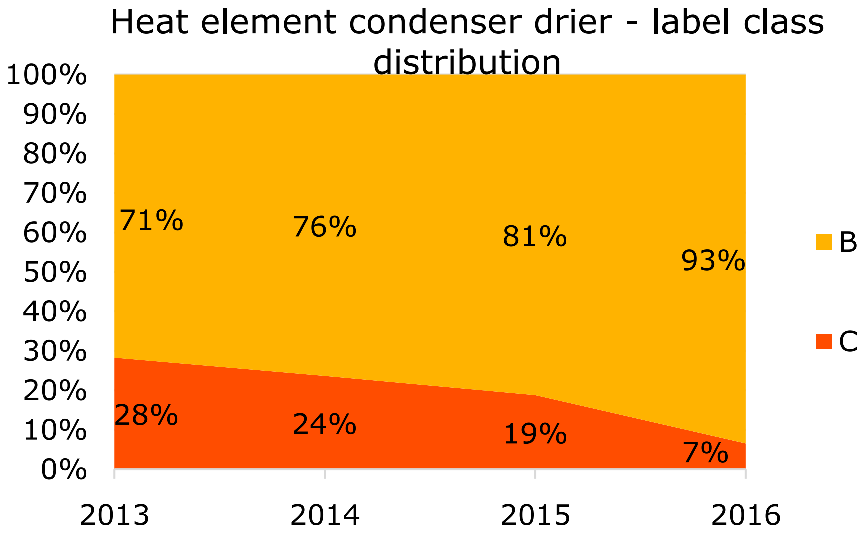

Figure iii: Energy class distribution and development for heat element condenser tumble driers

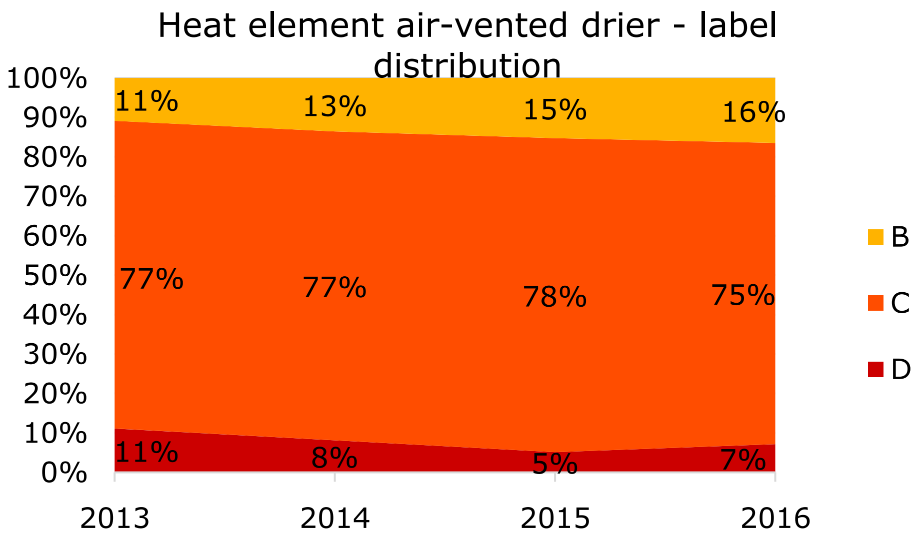

Figure iv: Energy class distribution and development for heat element air-vented tumble driers

The sales-weighted average rated capacity is increasing as it can be seen in Figure v. All but the gas driers are steadily increasing in rated capacity.

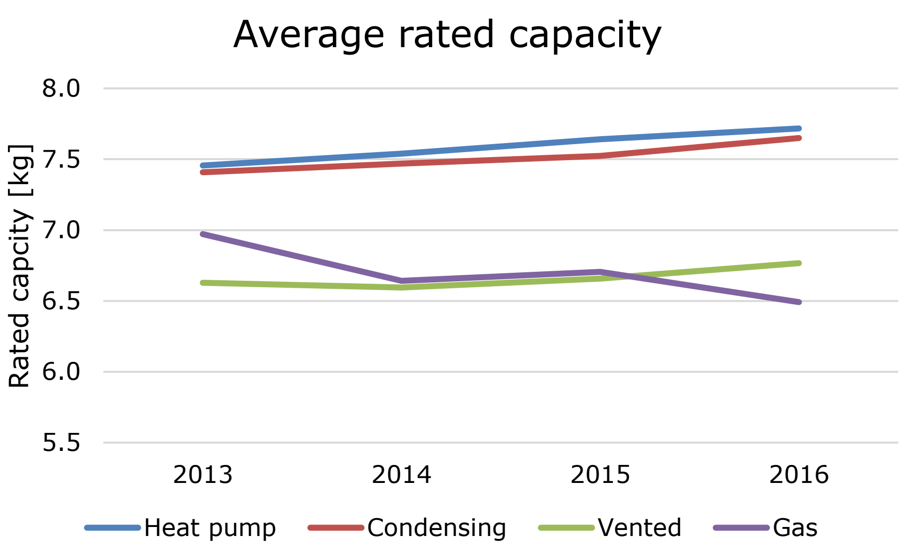

Figure v: Sales-averaged rated capacity for all drier types.

The consumer price including VAT was calculated from the data on unit sales and total market value collected by GfK (see Table v).

Table v: Unit retail prices in EUR for household tumble driers

Unit prices, EUR		2013	2014	2015	2016
Condenser	Heat pump	734	681	648	615
	Heating element	255	254	389	370
Air-vented	Heating element	245	338	266	248
	Gas-fired	245	338	465	374

The price of heat pump tumble driers has decreased steadily from 2013 to 2016, as the technology matured and took over a larger share of the market. This price decrease happened despite the increase of driers in energy classes A++ and A+++ (24% and 1% in 2013 compared to 62% and 14% in 2016).

The air-vented tumble drier with heat element technology stayed more or less on the same price level despite some fluctuations, and the label class distribution also stayed more or less constant over the four reported years with the majority in energy class C (75-78%).

The condenser tumble drier with heat element technology increased in price over the four years, which follows the market shifting to more efficient condenser tumble driers (approx. 20% of condenser tumble driers moving from C to B energy class within the same period).

User behaviour

The main parameters affected by user behaviour that are important to the energy and condensation efficiency of a tumble drier are:

- The average number of drying cycles per week
- The loading of the drier per cycle, i.e. how much is the machine filled in average with respect to its rated capacity
- The time the machine is left in left-on mode by the user before it is switched off
- Additionally, lint filter and heat exchanger cleaning frequency is important to ensure consistent performance of the machine, as failing to regularly do so will increase the energy consumption per cycle[5,6]

Two online surveys are available that cover a wide range of aspects concerning the user behaviour with regard to tumble driers in the EU: the 2009 preparatory study and the study conducted for APPLiA by InSite Consulting[7]. Some studies on washing behaviour are also available. These studies can be used to assess the general laundry behaviour and/or to validate the drying behaviour studies, since drying load is influenced by washing load.

Results from the drying studies are summarised in Table vi. Results from the washing studies are summarised in Table vii.

Note that the APPLiA study only covered people who owned a tumble drier. Similarly, the preparatory study consumer survey covered a sample of people with 86% owning a tumble drier. This is consequently far from the penetration rate of 23% found in task 2. Values in Table vi and Table vii thus mostly represent people owning a tumble drier and not the whole of EU28. This can also explain the large difference in drying loads between the APPLiA and the Alborzi study (i.e. % washing load that is dried in tumble drier).

There are generally two different ways the studies are conducted, by online surveys or by measuring the actual load used in each cycle ("Metering studies"). The online surveys from the preparatory study, APPLiA, and Alborzi have by far the largest statistical population and geographical scope, but also introduce subjectivity as these are not 'metering studies' and thus answers are being subject to personal bias and subjectivity.

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[5] According to input from stakeholders
[6] "EXPENSIVE MEASURES FOR THE ENVIRONMENT", Berge et al., RÅD & RÖN No. 7, 2012
[7] APPLiA and InSites Consulting. (2018). Tumble dryer usage and attitudes: A survey in 12 European countries (not publicly available). Draft version.

Table vi: Key findings for drying behaviour studies

Data source	***Preparatory study*[8]**	**APPLiA consumer questionnaire[93]**
Author	*PWC*	InSites Consulting
Data source, age	Online survey, 648 valid surveys, 2008.	Online survey, 2426 valid surveys, 2018.
Countries	UK, FR, PL	NL, UK, FR, GE, ES, IT, PL, CZ, HU, FI, SE, TR
Scope	Drying behaviour	Drying and washing behaviour
Average load/cycle	4.5kg / 3.4kg[9]	5.3[10]kg
Average nominal capacity	5.7 kg	7.1 kg
Frequency of use [Cycles/Person/Week]	0.7 (Summer) 1.1 (Winter)	0.6 (Summer) 0.8 (Winter)
Frequency of use [Cycles/Household/Week]	2.3 (Summer) 3.6 (Winter)	1.7 (Summer) 2.4 (Winter)
% washing load that is dryed in tumble drier during winter	50%	72%
% washing load that is dryed in tumble drier during summer	24%	51%

[8] Preparatory study for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16, Ecodesign of Laundry Dryers, PriceWaterhouseCoopers, 2009.

[9] The conducted online survey resulted in 4.5kg. 3.4kg was chosen after stakeholder consultation, to keep consistency with washing machine studies.

[10] Based on average loading %, and average machine capacity.

Table vii: Available studies on washing behaviours

Data source	Study 1 [11]	Study 2[12]	Study 3[13]	Study 4[14]
Author	Berkholz et al.	Krushwitz et al.	Alborzi et al.	P&G
Data source, age	30-day metering study, 100 households, 2007	28-day metering study, 236 households, 2009.	Online survey, 4843 valid surveys, 2015.	Metering study, 276 households, 2015
Countries	DE	DE	CZ, DE, FI, FR, HU, IT, PL, RO, SE, ES, UK	FR
Scope	Washing behaviour	Washing behaviour	Washing machines, drying behaviour	Washing machines
Average washing load/cycle	3.4kg	3.3kg	5.7kg[15]	3.24kg
Average capacity (Washing machine)	5kg	5kg	6.5kg	6.24kg
Frequency of use [Cycles/Person/Week]	1.7	1.7	1.5	-
% washing load that is dried in tumble drier during winter	-	-	19%	-
% washing load that is driedin tumble drier during summer	-	-	11%	-

In general, the average lifetime of household equipment is falling, and the lifetime has declined from 14.1 years to 13.0 years between 2004 and 2012 of large household appliances. This highest reduction in life time was observed for freezers and tumble driers where the lifetime decreased from 18.2 to 15.5 years and 13.6 to 11.9, respectively. So, the average lifetime of tumble driers in the current study is reduced to 12 years from 13 years in the preparatory study. Regarding heat pump condenser driers, the lifetime seemed to be reduced of the first models available on the market but today the manufactures have

[11] Berkholz P., et al: Verbraucherverhalten und verhaltensabhängige Einsparpotenziale beim Betrieb von Waschmaschine, Shaker-Verlag, 2007
[12] Kruschwitz, A.; Karle, A.; Schmitz, A. & Stamminger, R. (2014). Consumer laundry practices in Germany. International Journal of Consumer Studies, 38(3), pp. 265–277.
[13] A Alborzi, F.; Schmitz, A. & Stamminger, R. (2017). Washing behaviour of European consumers 2017, *Shaker Verlag*
[14] Proctor & Gamle: Load Weight Study - France 2015, Workshop on how to improve testing methods for washing machines and washer-dryers, Annex 6, 2016.
[15] Calculated as a weighted average, based on consumer loading behaviour on physical loading capacity, fig. 87.

no indication to suggest the that heat pump condenser driers should have a shorter lifetime than other types of tumble driers. Based on a consumer study performed by APPLiA the durability of condenser heat pump driers is not expected to present particular issues and the consumers rarely experience any technical failures.

A way to improve the lifetime of household appliances is to design products that are easier and less costly to repair so it is more affordable for the consumers to repair than exchange appliances. Currently repair and maintenance are expected to be done by professionals and in some cases by the end-user. Whether measures that can facilitate repair have a positive effect on the environment can be difficult to quantify, but based on a Deloitte[16] study it seems like the following options have a positive effect:

- Measures to ensure provision of information to consumers on possibilities to repair the product
- Measures to ensure provision of technical information to facilitate repair to professionals
- Measures to enable an easier dismantling of products
- Measures to ensure availability of spare parts for at least a certain amount of years from the time that production ceases of the specific models
- Different combination of the above-mentioned options

Technology overview

No major technical improvements at product level have emerged on the market for tumble driers since the preparatory study. The four main types of tumble driers, air-vented with heating element, air-vented with gas combustion, condensing with heating element and condensing with heat pump still exist. However, very few models of gas-fired tumble driers have been available for sale on the EU market and no major developments in this type of drier has been made in the past 10 years[17].

The focus in this task was to look at the different components and the developments that have been made.

The tumble drier unit consists of multiple components which can be of different types and qualities. Some are found in all tumble driers types and from these, the following components and their configurations have a major influence on the energy consumption:

- The motor type and setup

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[16] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.

[17] According to input from industry

- The presence of variable speed drives for fans and drum motors
- The controller, including humidity sensor components
- The drum design and sealing method
- The cleaning of lint filters and heat exchangers

Additionally, for condensing driers:

- Air to air heat exchanger type, material, and size

And furthermore, for heat pump condensing driers

- Compressor size, type and motor

Based on input from industry[18], Table viii shows a list of the major components and technologies having an impact on the energy efficiency of the drier. Each component/technology and relevant improvement options are described in more details in section 4.1.1.

[18] Questionnaire sent to APPLiA members on technologies during months February-March 2018

Table viii: List of components for the average tumble drier.
HP-C = Condensing heat pump drier, HE-C = Condensing heating element drier, HE-V = air-vented heating element drier, GA-V = air-vented gas fired drier.

Tumble drier technology/Component	Average drier on the market	*Relevant for*			
		HP-C	**HE-C**	**HE-V**	**GA-V**
MOTORs					
Motor type setup (one or multiple)	One	x	x	x	x
Motor type (drum)	AC-Induction	x	x	x	x
Motor type (compressor)	AC-Induction	x			
↳ If permanent magnet, has RER	No	x	x	x	x
VSD on motor drum drive	No	x	x	x	x
VSD on motor fans	No	x	x	x	x
VSD on compressor motor	No	x			
CONTROLLER					
Type of automatic controller	Automatic moisture sensor controller (direct way)	x	x	x	x
HEAT EXCHANGER (Air to air)					
Heat exchanger material	Aluminium		x		
Heat exchanger type	Plate-fin		x		
Self-cleaning heat exchangers	No		x		
HEAT EXCHANGER (Refrigerant - air)					
Heat exchanger material	Aluminium fins + copper tubes	x			
Heat exchanger type	Fin-and-tube	x			
Self-cleaning heat exchangers	No	x			
COMPRESSOR					
Compressor size	400-600 W	x			
DRUM					
Drum material	Steel	x	x	x	x
Direct Drive	No	x	x	x	x
Drum leakage	High/Medium	x	x		
USER INTERFACE					
Eco-mode program	No	x	x	x	x
FILTERS[19]					
Anti-clogging design	No	x	x	x	x

Table ix shows the BAT for each component. Note that the heat pump driers *always* outperform the other types and should hence still be classified as the BAT tumble drier.

[19] Both the primary lint filter, and the condenser lint filter for HP-C driers without self-cleaning heat exchangers.

Table ix: List of components for the BAT-tumble drier.
HP-C = Condensing heat pump drier, HE-C = Condensing heating element drier, HE-V = air-vented heating element drier, GA-V = air-vented gas fired drier.

Tumble drier technology/Component	BAT-Tumble drier	*Relevant for*			
		HP-C	**HE-C**	**HE-V**	**GA-V**
MOTOR					
Motor type setup (One or multiple)	One / Multiple	x	x	x	x
Motor type (Drum)	BLDC[20]	x	x	x	x
Motor type (Compressor)	BLDC[149]				
↳ If permanent magnet, has RER	No	x	x	x	x
VSD on motor drum drive	Yes	x	x	x	x
VSD on compressor motor	Yes	x			
CONTROLLER					
Type of automatic controller	Automatic moisture sensor controller (direct way)	x	x	x	x
HEAT EXCHANGER (Air to air)					
Heat exchanger material	Aluminium		x		
Heat exchanger type	Plate-fin		x		
Self-cleaning heat exchangers	No		x		
HEAT EXCHANGER (Refrigerant - air)					
Heat exchanger material	Aluminium fins + cobber tubes	x			
Heat exchanger type	Fin-and-tube	x			
Self-cleaning heat exchangers	No / Yes	x			
COMPRESSOR					
Compressor size	400-600 W	x			
DRUM					
Drum material	Stainless Steel	x	x	x	x
Direct Drive	No	x	x	x	x
Drum leakage	Low (<10%)	x	x		
USER INTERFACE					
Eco-mode program	Yes	x	x	x	x
FILTERS[143]					
Anti-clogging design	Yes	x	x	x	x

Regarding improved resource efficiency at End-of-Life different approaches can be implemented. Several options are available for design improvements and covers both more holistic guidelines and product specific suggestion.

The awareness regarding critical materials is increasing, and the Commission carries out a criticality assessment at EU level on a wide range of non-energy and non-agricultural raw

[20] A synchronous permanent magnet motor, i.e. brushless permanent magnet motor (BLDC). Can also be referred to as ECM/PMSM

materials. In 2017, the criticality assessment was carried out for 61 candidate materials (58 individual materials and 3 material groups: heavy rare earth elements, light rare earth elements and platinum group metals).

Tumble driers may contain several raw materials categorised as critical. Raw materials like vanadium and phosphorous are in some designations of steel used as alloying elements. These alloying elements are not included in this assessment as they are very difficult to quantify, and more obvious choices (due to larger quantities) are present such as:

- Printed circuit boards which may contain several critical materials such as gold, silver, palladium, antimony, bismuth, tantalum etc.[21]
- Compressor and heat exchangers which may contain copper (but according to manufactures it is possible also to produce heat exchangers with aluminium fins and tubes)
- Wires which may contain copper
- Motors which may contain copper and rare earth elements (magnets)

The composition of printed circuit boards is difficult to quantify but it is estimated as low grade for air tumbler driers. The product development of some tumble driers indicates higher grades of circuit boards in the future due to the implementation of more functions (network functions).

Printed circuit board are already targeted components according to the WEEE-Directive and compressors, heat exchanger and wires are already target due to their high amount of copper. Copper is also very important to remove before shredding to minimise the risk of copper contamination in the iron fraction since it directly can influence the mechanical properties of the recycled iron/steel[22]. Avoiding contaminants is one of the key points in design for recycling guidelines. If the heat exchanger consists of aluminium fins and cupper tubes the aluminium is likely to be lost in the recycling process, so it could be beneficial if the heat exchangers are made of the same material.

Furthermore, manufactures have indicated that the drum often are made of stainless steel (which may contain rare earths elements as alloying elements) only for the feel (perceived quality) and look of the drier. In principle it could be beneficial to use regular steel as long as the lifetime is not affected.

Material efficiency requirements can be very difficult to model, as the material efficiency is dependent on the waste handling system which again are dependent on the commodity

[21] http://www.wrap.org.uk/sites/files/wrap/Techniques%20for%20recovering%20printed%20circuit%20boards%2C%20final.pdf

[22] http://www.rmz-mg.com/letniki/rmz50/rmz50_0627-0641.pdf

prices. The current preferred waste processing is shredding but within the next 20 years it may change significantly, and it is therefore difficult in later tasks to quantify any measure towards improved material efficiency. Also, when products are shredded with other types of products the impact of any requirements toward a specific product may be reduced. Material requirements may therefore have greater effect if they are aligned across all product groups.

Dishwashers and washing machines may in the future have the most ambitious requirements regarding resource efficiency[23] according to proposed amendments to the current Ecodesign Regulations for these products[24]. These Regulations are not yet adopted but it seems to be the general trend. Previously there have been different requirements regarding information relevant for the disassembly but one of the greatest barriers towards increased repair and refurbishment is the lack of available spare parts[25]. By alignment with other Regulation it will be insured that all product groups constitute to transition from a linear economy to a more circular economy.

Though, the low collection rate of tumble driers[26] can challenge the improvement potential of any suggestions regarding resource efficiency since many products do not reach the desired recycling facility. The collection rate is expected to increase and reach the targets set out in the WEEE Directive[27] in 2019. The current low collection rates cannot be directly addressed in the Ecodesign Regulation since this is not related to the design of the product.

Based on the list of critical raw materials and the WEEE Directive the following components and materials are of special interest:

- Printed circuit boards which may contain several critical materials such as gold, silver, palladium, antimony, bismuth, tantalum etc.[28]
- Compressor and heat exchangers which may contain copper (but according to manufactures it is possible also to produce heat exchangers with aluminium fins and tubes)
- Wires which may contain copper
- Motors which may contain copper and rare earth elements (magnets)

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[23] Note that vacuum cleaners also have ambitious requirements with regard to durability and lifetime.
[24] Proposals was discussed at meetings in Consultation Forum on 18 and 19 December 2017. The working document where these suggestions are presented are available on: https://www.eceee.org/ecodesign/
[25] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.
[26] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselee&lang=en
[27] http://ec.europa.eu/environment/waste/weee/index_en.htm
[28] http://www.wrap.org.uk/sites/files/wrap/Techniques%20for%20recovering%20printed%20circuit%20boards%2C%20final.pdf

By alignment with other Regulations (specially with the suggested dishwasher and washing machine Regulation printed circuit boards are easily removed when they are larger than 10 cm^2 which also seems very beneficial from a critical resource perspective and supporting the WEEE Directive (see Annex II). Some requirements may be difficult to address from a market surveillance perspective because the requirements are difficult to control such as requirements of ease of dismantling. Though, these requirements are proposed in the dishwasher and washing machine ecodesign Regulations and the following is stated:

"Accessing components shall be facilitated by documenting the sequence of dismantling operations needed to access the targeted components, including for each of these operations, the type and the number of fastening techniques(s) to be unlocked, and tool(s) required."

II. Table of Contents

III. List of tables

IV. List of figures

V. Introduction to report

This is the interim report for the review of Ecodesign Regulation (EU) No 932/2012 and Energy Labelling Regulation (EU) 392/2012 for tumble driers and it is the first delivery of the specific contract. As specified in the contract the study follows the structure of the MEErP methodology of which the draft interim report concerns tasks 1 to 4 and is intended to create the basis for discussion at the first stakeholder meeting.

Task 1 outlines the scope of the Regulations and of the review study, including product categorisation, as well as the relevant standards and legislations, including those under development, related to tumble drier energy consumption and resource efficiency.

Task 2 gives an overview of the tumble drier market including sales, stock and base data on consumer costs, including stock backcasting and forecasting covered by available data. Furthermore task 2 presents an overview of market trends concerning product design and features and how they are affecting tumble driers performance considering the parameters shown in the energy label, energy class distribution and the energy efficiency of all products in scope of this review study.

Task 3 presents latest trends in consumer behaviour, lifetime and an overview of the current end-of-life practices for tumble driers. Consumer behaviour aspects presented are those affecting energy consumption and efficiency, such as loading habits. Furthermore, here it is discussed whether these aspects are properly reflected in test standards and measurements conditions. Tumble driers lifetime is also investigated, and whether there are differences in lifetime between different heating technologies, in particular for heat pump tumble driers. An analysis of the appropriateness of the current verification tolerances, as defined in Annex III and Annex V of the Ecodesign and Energy Labelling Regulations respectively, will be presented in an upcoming version of this report. This is introduced in this interim report but an analysis will be done once the results of the Round Robin Test (RRT) commissioned by industry is available (expected later in the spring of 2018).

Task 4 reviews the technical aspects of tumble driers and outlines the current technology levels in terms of average and best available technologies (BAT), as well as which technologies are expected to enter the market (best not yet available technology, BNAT). Besides the effect on energy consumption, the technologies are also reviewed in terms of resource efficiency. This analysis is the basis to define the base case technology, which will be presented and used in subsequent tasks to define the base cases.

VI. General background

The Commission's Regulation (EU) No 932/2012 with regard to ecodesign requirements for household tumble driers entered into force in October 2012 (with requirements applicable from November 2013) with the following timeline:

- From November 2013, specific ecodesign requirements on the Energy Efficiency Index (EEI) for all household tumble driers and on the condensation efficiency for condenser household tumble driers applied.
- From November 2014, generic ecodesign requirements on calculation of energy consumption and information provided in booklet applied for all household tumble driers.
- From November 2015, more stringent EEI and condensation efficiency requirements applied.

The Commission's Regulation No 392/2012 with regard to Energy Labelling of household tumble driers entered into force in May 2012.

The objective of the Regulations is to ensure the placing on the market of technologies that reduce the life-cycle environmental impact of tumble driers, leading to estimated electricity savings of up to 9.5 TWh per year in 2030, corresponding to 4.2 Mt CO_2-eq per year, according to the Commission staff Working Document derived from the Impact Assessment[29].

The Regulations cover electric mains-operated and gas-fired household tumble driers and built-in household tumble driers, including those sold for non-household use. Household combined washer-driers and household spin-extractors are exempted.

The Ecodesign Regulation was amended by the horizontal Regulation (EU) 2016/2282 with regard to the use of tolerances in verification procedures, while the energy labelling Regulation was amended by two horizontal Regulations: Regulation (EU) 518/2014 regarding labelling of energy-related products on the internet and Regulation (EU) 2017/254 with regard to the use of tolerances in verification procedures.

Both the ecodesign and the energy labelling Regulations are scheduled for review, and this review study therefore aims to do so by updating the existing preparatory study on household tumble driers published in March 2009. This is done following the principles of the MEErP method. Additionally, this study should:

- Assess the verification tolerances set out in the Regulations

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[29] https://ec.europa.eu/energy/sites/ener/files/documents/td_impact_assessment.pdf

- Assess the efficiency of air-vented appliances
- Assess resource efficiency aspects (most likely disassembly, recyclability, reparability and durability) following the adoption of the Circular Economy Package in December 2015[30] and the new Ecodesign Working Plan 2016-2019[31]
- Evaluate the impact of the existing Regulations, including an analysis of the relevant questions, answers, evidences based related to the basic criteria (efficiency, effectiveness and relevancy) which are specific to evaluations in the context of the 'Better Regulation' framework.

[30] https://ec.europa.eu/commission/publications/european-commission-proposals-circular-economy_en
[31] https://ec.europa.eu/energy/sites/ener/files/documents/com_2016_773.en_.pdf

1. Task 1: Scope

Task 1 report follows the MEErP methodology and the specific items requested by the European Commission. It includes the following:

1. Product scope: Identification and description of relevant product categories and definition of the product scope and categorisation based on Regulations, previous studies and market terms.
2. Legislation: Update of relevant legislation on EU, Member State and third country level.
3. Test standards: Update and description of relevant test and measurement standards on EU, Member State and third country level, including those on resource efficiency aspects.

The review of legislations and test standards include those relevant to the Ecodesign and Energy Labelling Regulations on tumble driers[32].

1.1 Product scope

The current scope of Commission Regulation (EU) No 932/2012 covers electric mains-operated and gas-fired household tumble driers and built-in household tumble driers, including those sold for non-household use.

The current scope of Commission Delegated Regulation (EU) No 392/2012 covers electric mains-operated and gas-fired household tumble driers and built-in household tumble driers, including those sold for non-household use.

The definition of tumble driers is presented and discussed in the next sub-section.

1.1.1 Definitions from the Regulations

The tumble drier Ecodesign Regulation (EU) No 932/2012 and Energy Labelling Regulation (EU) 392/2012 employ identical definitions for household tumble driers , which are listed below.

Products within the scope of the Regulations are defined as:

Household tumble drier means an appliance in which textiles are dried by tumbling in a rotating drum through which heated air is passed and which is designed to be used principally for non-professional purposes.

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[32] Commission Regulation (EU) No 932/2012, available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0932&from=EN and Commission Delegated Regulation (EU) No 392/2012, available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0392&from=EN

Built-in household tumble drier means a household tumble drier intended to be installed in a cabinet, a prepared recess in a wall or a similar location, requiring furniture finishing.

Air-vented tumble drier means a tumble drier that draws in fresh air, passes it over the textiles and vents the resulting moist air into the room or outside.

Condenser tumble drier means a tumble drier which includes a device (either using condensation or any other means) for removing moisture from the air used for the drying process.

Automatic tumble drier means a tumble drier which switches off the drying process when a certain moisture content of the load is detected, for example through conductivity or temperature sensing.

Non-automatic tumble drier means a tumble drier which switches off the drying process after a predefined period, usually controlled by a timer, but which may also be manually switched off.

Defined products not within the scope of the Regulations:

Household combined washer-drier means a household washing machine which includes both a spin extraction function and also a means for drying the textiles, usually by heating and tumbling.

Household spin-extractor, also known commercially as 'spin-drier', means an appliance in which water is removed from the textiles by centrifugal action in a rotating drum and drained through an automatic pump and which is designed to be used principally for non-professional purposes.

Other important definitions are:

Programme means a series of operations that are predefined, and which are declared by the manufacturer as suitable for drying certain types of textiles

Cycle means a complete drying process, as defined for the selected programme.

Programme time means the time that elapses from the initiation of the programme until the completion of the programme, excluding any end-user programmed delay

Rated capacity means the maximum mass in kilograms, indicated by the manufacturer in 0,5 kilograms increments of dry textiles of a particular type, which can be treated in a household tumble drier with the selected programme, when loaded in accordance with the manufacturer's instructions

Partial load means half of the rated capacity of a household tumble drier for a given programme.

Condensation efficiency means the ratio between the mass of moisture condensed by a condenser tumble drier and the mass of moisture removed from the load at the end of a cycle

Off-mode means a condition where the household tumble drier is switched off using appliance controls or switches accessible to and intended for operation by the end-user during normal use to attain the lowest power consumption that may persist for an indefinite time while the household tumble drier is connected to a power source and used in accordance with the manufacturer's instructions; where there is no control or switch accessible to the end-user, 'off-mode' means the condition reached after the household tumble drier reverts to a steady-state power consumption on its own.

Left-on mode means the lowest power consumption mode that may persist for an indefinite time after completion of the programme without any further intervention by the end-user besides unloading of the household tumble drier;

Equivalent household tumble drier means a model of household tumble drier placed on the market with the same rated capacity, technical and performance characteristics, energy consumption, condensation efficiency where relevant, standard cotton programme time and airborne acoustical noise emissions during drying as another model of household tumble drier placed on the market under a different commercial code number by the same manufacturer.

Standard cotton programme means the cycle which dries cotton laundry with an initial moisture content of the load of 60 % up to a remaining moisture content of the load of 0 %.

1.1.2 Definitions from preparatory study

Besides the above definitions from the Regulations, the preparatory study sets out a number of relevant definitions, which defines tumble driers across the above categories:

Electric tumble drier: the drier generally uses a coiled wire heated with electric current. The amount of electric current is varied to adjust the temperature.

Gas tumble drier: a gas burner is used the heat the air. The air temperature can be altered by adjusting the size of the gas flame or, more commonly, by merely extinguishing and relighting it.

Air condenser drier: The ambient room air is used as a heat sink. It is blown across the outside of the heat exchanger to cool and dehumidify the warm air used for the drying process. This was the most common type of condenser drier in the market at the time of the preparatory study.

Water condenser drier: Water is used to cool the warm air and condense the moisture. At the time of the preparatory study there was no tumble drier on the market using this technology, but for washer-driers this technology was prevalent.

Heat pump condenser drier: The heating and condensing is performed by the hot and cold plates of a heat pump. At the time of the preparatory study there were only a few models of tumble driers available on the market based on this technology.

1.1.3 Definitions in EN 61121:2013 standard – Tumble driers for household use – Methods for measuring the performance

This EN standard provides some additional definitions which are also relevant to the aims of this study, listed below:

Test load means textiles load used for testing

Pre-treatment means processing of a new test load prior to its first use to avoid rapid changes of characteristics during tests

Conditioning means brining the test load into thermodynamic equilibrium with the defined ambient air conditions of temperature and humidity; Note: The process of conditioning is not the same as "wetting".

Test run means single performance assessment

Test series means group of test runs on a tumble drier which, collectively, are used to assess the performance of that tumble drier.

Operation means each performance of a function that occurs during the tumble drier drying process such as heating up, drying, cooling, anti-creasing.

End of the programme means moment in time when the tumble drier indicates the programme is complete and the load is accessible to the user[33].

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[33] **Note 1**: Where there is no such indicator and the door is locked during operation, the programme is deemed to be complete when the load is accessible to the user. Where there is no indicator and the door is not locked during operation, the programme is deemed to be complete when the power consumption of the appliance drops

Cycle time means period of time from the initiation of the programme (excluding any user programmed delay) until all activity ceases. Activity is considered to have ceased when the power consumption reverts to a steady state condition that persists indefinitely without user intervention. If there is no activity after the end of the programme, the cycle time is equal to the programme time[34].

Normalization means processing of a test load after a pre-determined number of cycles to bring the test load to a normal state prior to testing.

Test load mass means actual mass of the test load.

Nominal test load mass means mass of dry textiles of a particular type for which the performance of the tumble drier will be tested (rated capacity or part load). Target value toward which the conditioned test load mass will be adjusted.

Moisture content means ratio of the difference between test load mass and the conditioned test load mass to the conditioned test load mass expressed in percent.

Initial moisture content means moisture content of a test load prior to a test run.

Final moisture content means moisture content of a test load at the end of a test run.

Rated voltage means voltage assigned to the appliance by the manufacturer.

1.1.4 PRODCOM categories

The PRODCOM database is the official source of data regarding production and sales of products in the EU according to the MEErP methodology. For tumble driers, the first data entry in the database was in 1995 and the latest in 2016. From 2008 the PRODCOM database switched from the NACE Rev. 1.1 (Statistical Classification of Economic Activities in the European Community, Revision 1.1) nomenclature to the NACE Rev. 2.0[35], which meant that most product categories were rearranged. The Product categories relevant for this review from both versions of the database are shown in Table 1.

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to a steady state condition and it is not performing any function. For non-automatic tumble dryers, the programme is deemed to be complete when it is stopped by the operator. **Note 2**: An indication of the end of the programme may be in the form of a light (on or off), a sound, an indicator shown on a display or the release of a door or latch. In some tumble dryers there may be a short delay from an end of the programme indicator until the load is accessible by the user.

[34] **Note**: Cycle time includes any activity that may occur for a limited period after the end of the programme. Any cyclic event that occurs indefinitely is considered to be steady state.

[35] http://ec.europa.eu/eurostat/web/nace-rev2/transition

Table 1: Product categories used in the PRODCOM database

NACE Rev 1.1 (1995-2007)	
29.71	Manufacture of electric domestic appliances
└29.71.13	Cloth washing and drying machines, of the household type
└29.71.13.70	Drying machines of a dry linen capacity ≤ 10 kg
NACE Rev 2.0 (2008-2016)	
27.51.13.00	Cloth washing and drying machines, of the household type

As seen from Table 1, the NACE rev. 1.1 clearly differentiates between washing machines and drying machines, which has a specific category. Machines that both wash and dry are grouped with washing machines. From 1995 to 2002 the data was only collected for the EU-15 countries, and hence the EU-28 data is available from 2003 and forward.

In the NACE rec. 2.0 there is only one category for household washing and drying machines, and collection of separate data in the specific categories has been discontinued. It is therefore not possible to single out the tumble driers from this aggregated category in the NACE Rev 2.0 dataset, which therefore cannot be used for market analysis in this review study.

In both versions of the database there are also categories for washing and drying machines intended for manufacturing or industrial purposes, which are not mentioned here as they are not relevant for this study. Neither of the classifications allow to differentiate between all relevant product groups such as the different tumble drier technologies defined in the Regulations.

1.1.5 Description of products

The primary distinction between tumble driers is the technology that they use, which is also reflected by the categorisation used in the Regulations. In the below sections, the five main types of tumble driers identified will be described in more detail to provide explanation of the terms used in the report.

Air-vented tumble driers

Air-vented tumble driers, as shown in **Figure 1** are the traditional type of drier, which draws in air from its surrounding room and then heats it and blow it through the clothes to remove moisture from it. The humid air is then exhausted through a ventilation duct in the wall to the outdoors. Hence the vented driers have to be fitted with a hose connected to a wall or window through which the humid air from the drum can be exhausted.

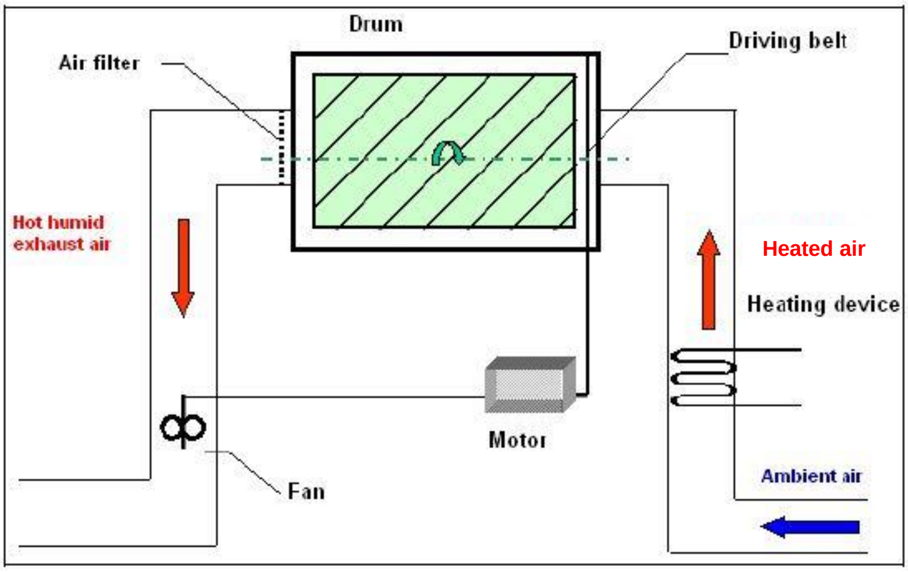


Figure 1: Air-vented tumble drier. Source: Adapted by PWC (2009)36 from (Essaoui, 2001)[37]

Condenser tumble driers

Condenser tumble driers work through a condensation process where air is recirculated rather than released to the outdoors. The water is condensed out of the moist air coming from the drum by cooling it down in a heat exchanger (using ambient air as heat sink) and the air is reheated and recirculated back to the drum, as shown in Figure 2. The water is either deposited in a container, which should then be emptied by the user, or the drier is connected to a drain to which the water is released. The condenser tumble drier does therefore not have to be placed near a wall, but it is convenient to place them near a drain.

[36] PWC: Ecodesign of Laundry Driers, Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16, Final Report, March 2009
[37] Essaoui: Présentation du sèche-linge, Fagor-Brandt internal documentation, 2001

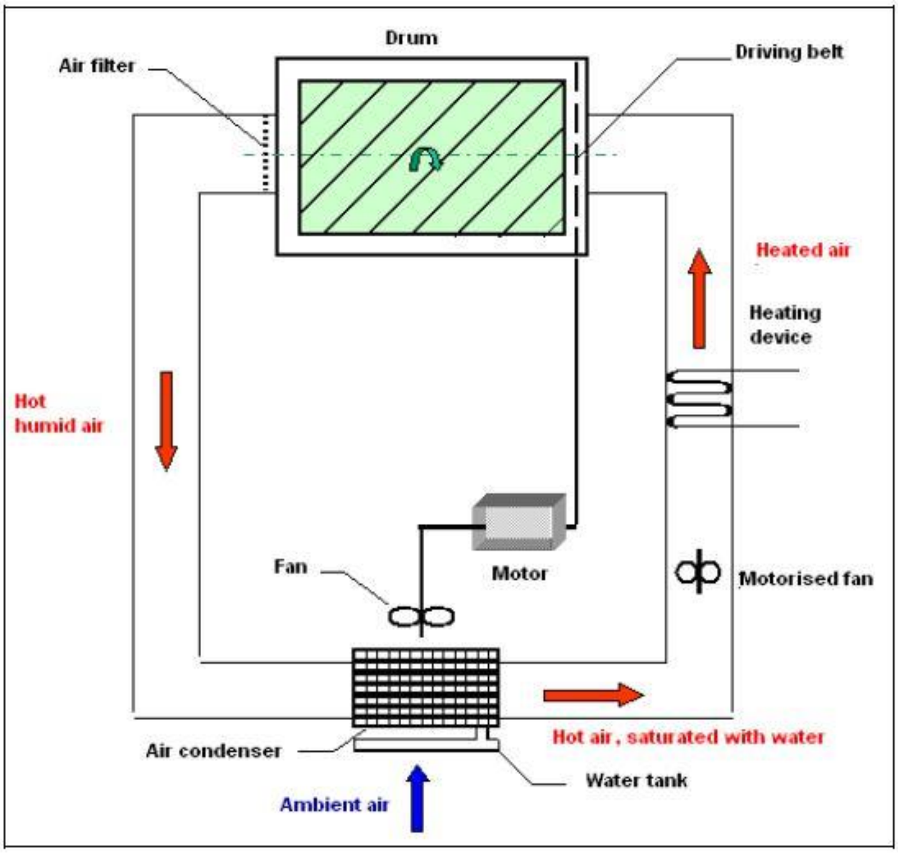


Figure 2: Condenser tumble drier. Adapted by PWC (2009) from (Essaoui, 2001)

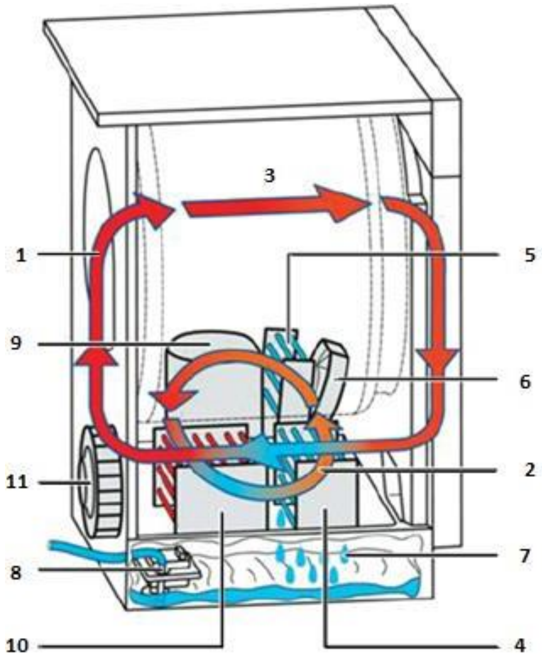
Heat element tumble driers

Heat element tumble driers use a standard electric heat element to heat the air going into the drum. The heat element can be used in both air-vented and condenser driers and is often a metal coil or plate as seen in Figure 3. The heat element heats up the air as it passes through.

Figure 3: Example of a plate heating element

Heat pump tumble driers

In heat pump driers, the hot moist air from the drum is passed through a heat pump. The heat pump removes the heat from the hot moist air causing the water in it to condense, and the removed heat is recycled to re-heat the now dry air before it goes back in the drum. The heating and cooling is achieved through a compression-expansion cycle, which requires electricity and utilises a refrigerant in a closed-loop to transfer the energy. This cycle is shown in Figure 4.



1	Air circuit; dry, hot air entering drum
2	Refrigerant circuit
3	Drum; moisture removed from clothes, taken up by air
4	Heat exchanger; the heat energy transferred from air to refrigerant, condensing out water
5	Speed cooler
6	Power cooler
7	Condensed water
8	Drain pump, removing the condensed water
9	Compressor; the refrigerant is compressed to high pressure and high temperature
10	Heat exchanger; the hot refrigerant is used to heat the air
11	Ventilator

Figure 4: Heat pump drier. Source: ResearchGate (2012)[38]

Gas-fired tumble driers

The gas tumble drier technology is very similar to the heating element air-vented technology, except the electric heating element is replaced by a gas flame. Gas tumble driers are always air-vented (i.e. cannot use condensing technology) due to the combustion gasses.

1.1.6 Summary of scope

The overall scope of this review study is proposed to remain the same as the scope of the current Regulations. The different tumble drier categories can be seen in Figure 5. The driers can be classified either based on the heating technology (gas, heat element or heat pump) or on the mechanism used to remove the clothes' moisture (i.e. drier technology, which can be air-vented or condensing). In the case of heat element driers, the categories overlap (see Figure 5).

In the Ecodesign Regulation (EU) No 932/2012, the requirements are more stringent for condenser tumble driers than for air-vented driers, and therefore the product classification is only relevant at drier technology level by defining clearly the differences

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[38] https://www.researchgate.net/figure/254334342_fig2_FIG-2-Schematic-of-a-heat-pump-drying-system-1-process-circuit-2-compressor-3 and https://www.researchgate.net/publication/254334342_Advancements_in_Drying_Techniques_for_Food_Fiber_and_Fuel (courtesy of Bosch Siemens Inc., Germany)

between air-vented and condenser tumble driers. However, the methodology for calculating the weighted energy consumption is different for gas-fired household tumble driers, Regulationwhich is the same case for the Energy Labelling Regulation (EU) 392/2012, where there are three different tumble driers labels for air-vented, condenser and gas-fired household tumble driers respectively and there is a different calculation methodology for energy consumption of each types.

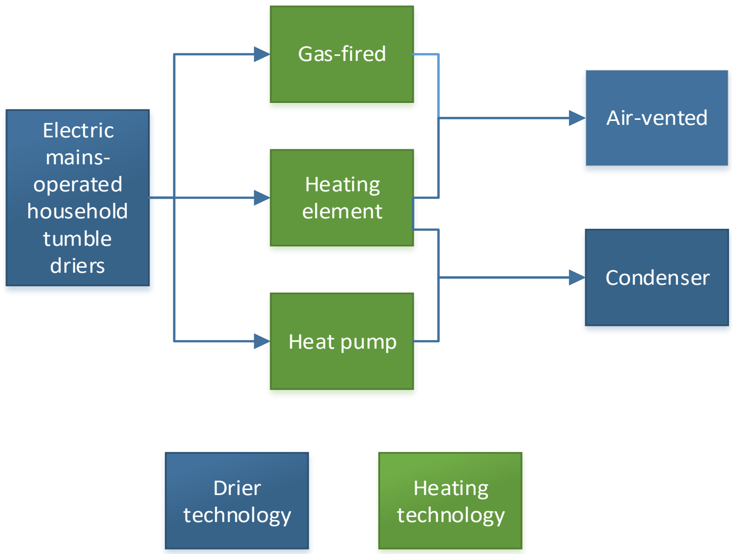

Figure 5: Overview of tumble driers classification

Heating technologies are important to consider for the assessment of technologies. They have a strong influence on the driers' energy efficiency, as well as on the resource efficiency, since they influence the materials used.

1.2 Review of relevant legislation

1.2.1 EU Directive 2009/125/EC – Ecodesign for Energy-Related Products[39]

The Ecodesign Directive provides consistent EU-wide rules for improving the environmental performance of energy-related products placed on the EU market. This EU-wide approach ensures that Member States' follow the same Regulations so that potential barriers to internal EU trade are removed.

The Directive's main aim is to provide a framework for reducing the environmental impacts of products throughout their entire life cycle. As many of the environmental impacts associated with products are determined during the design phase, the Ecodesign Directive aims to bring about improvements in environmental performance through mandating changes at the product design stage.

[39] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0125&from=EN

The Ecodesign Directive is a framework Directive, meaning that it does not directly set minimum requirements. Rather, the aims of the Directive are implemented through product-specific Regulations, which are directly applicable in all EU member states. For a product to be covered under the Ecodesign Directive it needs to meet the following criteria:

- have a volume of sales that exceeds 200,000 units per year throughout the internal European market
- have a significant environmental impact within the internal market
- present significant potential for improvement in environmental impact without incurring excessive costs

Commission Regulation (EU) No 932/2012[40] regarding ecodesign requirements for household tumble driers, establishes energy efficiency requirements for electric mains-operated and gas-fired household tumble driers and built-in household tumble driers, including those sold for non-household use. The Regulation does not apply to household combined washer-driers and household spin-extractors. The requirements in the Regulation have been introduced in two tiers which are:

- From 1 November 2013, for all household tumble driers:
    - The energy efficiency index (EEI) shall be < 85
- From 1 November 2015, for condenser household tumble driers:
    - The energy efficiency index (EEI) shall be < 76
    - The weighted condensation efficiency shall be ≥ 70 %

Besides these specific requirements, the Regulation sets out some generic requirements. These are requirements regarding which standard programme the different calculations shall be based on as well as information requirements.

- The basis for calculating the energy consumption and other parameters, are set to a cycle that dries cotton laundry with an initial moisture content of 60%, down to a moisture content of 0%
- This cycle shall be clearly identifiable on the programme selecting device as the "Standard cotton programme" (Can be done with a symbol, or a combination hereof).
- This cycle shall be set as the default cycle for tumble driers with automatic programme selection functions.
    - If the drier is automatic, this this cycle should be used automatic.

[40] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0932&from=EN

Furthermore, requirements for the booklet of instructions provided by manufactures shall include:

- Information about the "standard cotton programme", and that it is the most efficient programme for drying wet cotton laundry
- The power consumption of the off-mode and left-on mode
- Indicative information on the programme time and energy consumption for the main drying programmes at full, and, if applicable, partial load.

The tolerance-levels determined in Regulation 932/2012 for the purpose of verification of compliance, are set to 6% for all parameters listed in the Regulation. These are:

- weighted annual energy consumption
- weighted energy consumption
- weighted condensation efficiency
- weighted programme time
- power consumption in off-mode and left-on mode
- duration of the left-on mode

Commission Regulation (EU) No 2016/2282[41] with regard to the use of tolerances in verification procedures specifies that the tolerance-levels determined for the purpose of verification of compliance, are only allowed to be used by market surveillance authorities in the context of reading measurement results, rather than by producers or suppliers for the purpose of establishing values for the technical documentation or in interpreting these values with a view to achieving compliance.

Commission Regulation (EC) No 640/2009 incl. amendment (EU) No 4/2014[42] with regard to ecodesign requirements for electric motors and its amendment Commission Regulation (EU) No 4/2014[43]. The current scope includes electric one- or three-phase AC motors with output in the range 0.75-375 kW. This means that motors in tumble driers are currently not covered by the Motor Regulation (specifically, the motors for driving the drum and the fans for the hot and cooling air). Electric motors in the compressors for heat pump driers are not covered by the Motor Regulation , cf. article 1 in the Regulation (point 2(b)).

The most recent results from Lot 11 and Lot 30 study[44] show that the scope of the foreseen revised Motor Regulation will probably include single speed motors with rated outputs from

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[41] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R2282&from=EN
[42] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R0640&from=EN and http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0004&from=EN
[43] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0004&from=EN
[44] https://www.eceee.org/ecodesign/products/electricmotors/ and https://www.eceee.org/ecodesign/products/special-motors-not-covered-in-lot-11/

0.12kW to 1000kW, as well as including motors equipped with variable speed drives. This would include some motors used in drum drives and fans in tumble driers in the foreseen new Motor Regulation. In this case the motors used in tumble driers would have to comply with the IE3 efficiency levels, shown in Annex 1 in the current Motor Regulation.

Commission Regulation (EU) No 1275/2008[45] regarding ecodesign requirements for standby and off mode, and networked standby, electric power consumption of electrical and electronic household and office equipment.

EU ecodesign requirements are mandatory for all manufacturers and suppliers wishing to place on the market products consuming electric power in standby and off mode in the EU. A wide range of products, e.g. computers, TVs, audio and video equipment, white goods and electric toys can have standby modes, so the Regulation is horizontal and covers many products. The complete list of products is presented in Annex I of the Regulation, where clothes driers are explicitly mentioned. The Regulation is entering into force in stages, and all but the last stage (in 2019) is currently active. The requirements for products listed in Annex I is:

- Standby and off mode ≤ 0.5 Watts
- Standby with display ≤ 1 Watts
- Networked standby ≤ 3 Watts

Standby is here defined as a condition where the equipment is connected to the mains power source, depending on energy input from the mains power source to work as intended and provides only the following functions, which may persist for an indefinite time:

1. Reactivation function, or reactivation function and only an indication of enabled reactivation function, and/or:
2. Information or status display.

Off mode is here defined as a condition in which the equipment is connected to the mains power source and is not providing any function; the following shall also be considers as off mode:

1. Conditions providing only an indication of off-mode condition
2. Conditions providing only functionalities intended to ensure electromagnetic compatibility pursuant to Directive 2004/108/EC of the European Parliament and of the Council.

[45] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008R1275-20170109&from=EN

From 2017, all covered appliances are required to have a power management system which turns the equipment into standby or off-modes after the shortest possible period of time, when the equipment is not providing the main function.

For appliances connected to the internet, an option for deactivating the wireless network connection shall be included. Furthermore, a power management system for the network capabilities of the appliance, should be included as well. This system should switch the appliance into networked standby before 20 minutes after use. This is relevant for some of the newer tumble drier models, which are equipped with network capabilities for remote start operation.

Tumble driers do in some models offer "delayed start" options. These modes are not covered in the standby Regulation, as this mode does not last for an indefinite time. Similarly, tumble driers have a left-on mode, after operation. This mode is also not covered in the Regulation, as the mandatory power management system turns the appliance off after a set amount of time. Furthermore, left-on mode requires no further user intervention by the end-user, which happens when appliances are on standby, due to reactivation.

Left-on mode and off mode are indirectly regulated in the ecodesign and energy labelling Regulations of tumble driers are they are included in the EEI calculation.

The Standby Regulation is currently under revision where the scope and some of the requirements may be amended[46].

Commission Regulation (EU) No 206/2012 regarding air conditioners and comfort fans. The energy requirements set here are not applicable to heat pump tumble driers, as the temperature levels and system designs of an air conditioning system are very different from a drying process and should hence not be compared.

1.2.2 EU Regulation 2017/1369 setting a framework for energy labelling and replacing Directive 2010/30/EU[47]

Regulation 2017/1369 sets a framework for energy labelling of energy-related products and replaces Directive 2010/30/EU. The Directive required producers to label their products in terms of energy consumption on a scale of A – G, as well as inform of a number of other parameters, so that consumers could compare the efficiency of one products with that of another. The current energy labelling requirements for household tumble driers (Regulation 392/2012) are set in relation to Directive 2010/30/EU. The revised rules for energy labelling of household tumble driers will be issued under the new framework

[46] https://www.eceee.org/ecodesign/products/standby/
[47] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1369&from=EN

Regulation. For more information regarding Regulation 2017/1369 see subchapter 1.1.1 below.

In the future, all products will be labelled on a new, updated and clearer scale from A (most efficient) to G (least efficient). This system will gradually replace the current system of A+++ to G labels, which as a result of the technological development towards more energy efficient products in recent years no longer enables consumers to distinguish clearly between the most energy efficient items.

The new A – G scales for the different product categories will be issued through new, product-specific delegated Regulations. For the present study, this means that a rescaling must be performed for the products in scope, transferring them from the current A+++ – G scale to an A – G scale. As Regulation 2017/1369 stipulates, in order to encourage technological progress, the top class should be left empty at the moment of rescaling. In exceptional cases, where technology is expected to develop more rapidly, the two top classes should be left empty at the moment of introduction of the newly rescaled label. The latter is however not expected to be the case for the products in scope as current heat pump tumble driers already represent a highly efficient product.

The subject will be addressed later in this report, where calculations for the rescaling of tumble driers will be performed.

Commission Delegated Regulation (EU) No 392/2012[48] supplementing Directive 2010/30/EU regarding energy labelling of household tumble driers, establishes labelling and information requirements to tumble driers that are within the scope of Ecodesign Regulation 932/2012. Thus, requirements in the Regulation are set to air-vented, condenser and gas-fired household tumble driers, respectively.

In terms of energy efficiency, the following distribution of energy efficiency classes based on the energy efficiency index (IEE) is made in the Regulation. This distribution applies for all three types of tumble driers.

[48] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0392&from=EN

Table 2: Energy efficiency classes in Regulation 392/2012

Energy efficiency class	**Energy efficiency index (IEE)**
A+++ (most efficient)	EEI < 24
A++	24 ≤ EEI < 32
A+	32 ≤ EEI < 42
A	42 ≤ EEI < 65
B	65 ≤ EEI < 76
C	76 ≤ EEI < 85
D (least efficient)	85 ≤ EEI

The EEI is calculated as specified in the Regulation.

For condenser tumble driers, requirements are also made for condensation efficiency. The condensation efficiency class is determined on the basis of the weighted condensation efficiency (C_t), which is calculated as specified in the Regulation. The distribution of condensation efficiency class according to the weighted condensation efficiency (C_t) made in the Regulation can be seen in Table 3.

Table 3: Condensation efficiency classes in Regulation 392/2012

condensation efficiency class	**weighted condensation efficiency**
A (most efficient)	$C_t > 90$
B	$80 < C_t \leq 90$
C	$70 < C_t \leq 80$
D	$60 < C_t \leq 70$
E	$50 < C_t \leq 60$
F	$40 < C_t \leq 50$
G (least efficient)	$C_t \leq 40$

The Regulation also makes several information requirements. The information required to appear on the energy labels for all three categories of tumble driers is the following:

- supplier's name or trade mark
- supplier's model identifier, meaning the code, usually alphanumeric, which distinguishes a specific household tumble drier model from other models with the same trade mark or supplier's name
- the energy efficiency class, as defined in the Regulation (see Table 2)
- the head of the arrow containing the energy efficiency class of the household tumble drier shall be placed at the same height as the head of the arrow of the relevant energy efficiency class
- weighted annual energy consumption (AE_C) in kWh/year, rounded up to the nearest integer and calculated as specified in the Regulation
- information on the type of household tumble drier
- cycle time corresponding to the standard cotton programme at full load in minutes and rounded to the nearest minute
- rated capacity, in kg, for the standard cotton programme at full load, and
- the sound power level (weighted average value — L_{WA}), during the drying phase, for the standard cotton programme at full load, expressed in dB, rounded to the nearest integer.

Apart from these, the energy labels of condenser tumble driers must also include the condensation efficiency class, as defined in the Regulation (see Table 3).

The design of the energy labels for air-vented, condenser and gas-fired household tumble driers, respectively, as determined in Regulation 392/2012, can be seen in Figure 6.

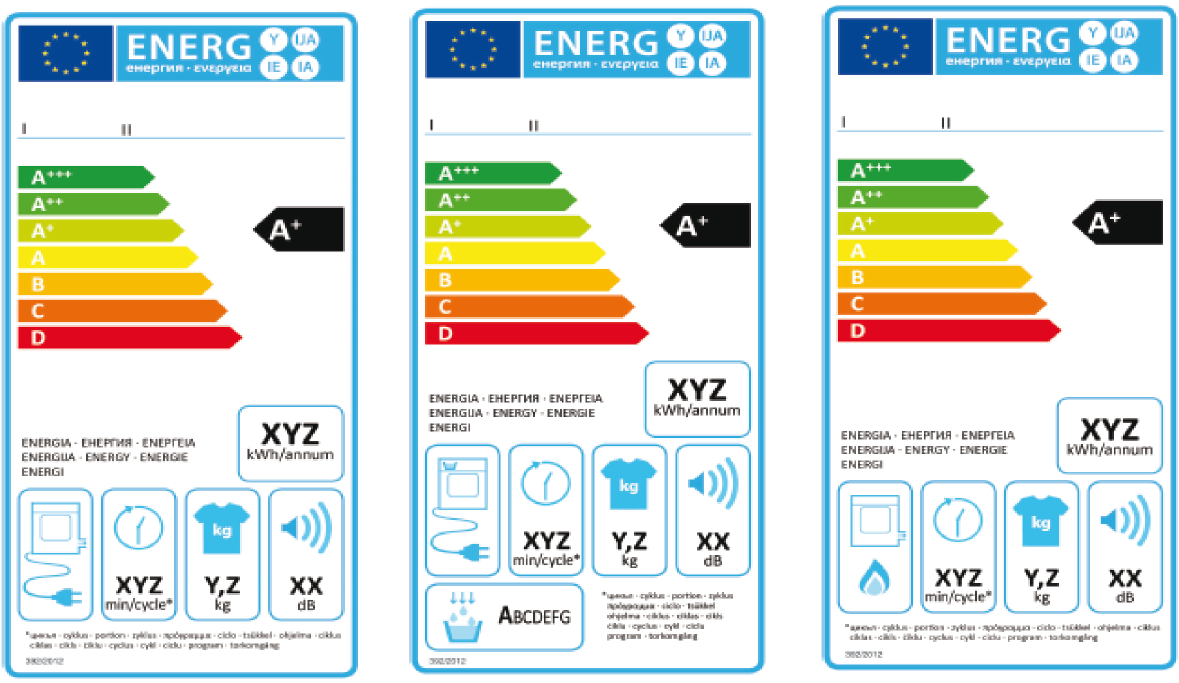

Figure 6: From left to right: the design of the energy labels for air-vented, condenser and gas-fired tumble driers as specified in Regulation 392/2012.

Apart from information requirements for the energy label itself, Regulation 392/2012 sets out requirements for information to be provided in cases where end-users cannot be expected to see the product displayed as well as information requirements for the product fiche, which are listed below:

1. The information in the product fiche of household tumble driers shall be given in the following order and shall be included in the product brochure or other literature provided with the product:
    a. Supplier's name or trade mark
    b. supplier's model identifier, which means the code, usually alphanumeric, which distinguishes a specific household tumble drier model from other models with the same trade mark or supplier's name;
    c. rated capacity in kg of cotton laundry for the standard cotton programme at full load;
    d. whether the household tumble drier is an air-vented, condenser or gas-fired household tumble drier;
    e. energy efficiency class in accordance with point 1 of Annex VI in the Regulation;
    f. for electric mains-operated household tumble drier:

        the weighted Annual Energy Consumption (AEc) rounded up to one decimal place; it shall be described as: 'Energy consumption "X" kWh per year, based on 160 drying cycles of the standard cotton programme at full and partial load, and the consumption of the low-power modes. Actual energy consumption per cycle will depend on how the appliance is used.';

        for household gas-fired tumble drier: the weighted Annual Energy Consumption (AEC(Gas)) rounded up to one decimal place; it shall be described as: 'Energy consumption "X" kWh-Gas per year, based on 160 drying cycles of the standard cotton programme at full and partial load. Actual energy consumption per cycle will depend on how the appliance is used'; and the weighted Annual Energy Consumption (AEC(Gas)el) rounded up to one decimal place; it shall be described as: 'Energy consumption "X" kWh per year, based on 160 drying cycles of the standard cotton programme at full and partial load, and the consumption of the low-power modes. Actual energy consumption per cycle will depend on how the appliance is used.

g. whether the household tumble drier is an 'automatic tumble drier' or 'non-automatic tumble drier

h. where the household tumble drier has been awarded an 'EU Ecolabel award' under Regulation (EC) No 66/2010, this information may be included;

i. the energy consumption (Edry , Edry½ , Egdry , Egdrya½, Egdry,a, Egdry½,a) of the standard cotton programme at full and partial load;

j. the power consumption of the off-mode (Po) and of the left-on mode (Pl) for the standard cotton programme at full load;

k. if the household tumble drier is equipped with a power management system, the duration of the 'left-on mode';

l. indication that the 'standard cotton programme' used at full and partial load is the standard drying programme to which the information in the label and the fiche relates, that this programme is suitable for drying normal wet cotton laundry and that it is the most efficient programme in terms of energy consumption for cotton;

m. the weighted programme time (Tt) of the 'standard cotton programme at full and partial load' in minutes and rounded to the nearest minute as well as the programme time of the 'standard cotton programme at full load' (Tdry) and the programme time of the 'standard cotton programme at partial load' (Tdry½) in minutes and rounded to the nearest minute;

n. if the household tumble drier is a condenser tumble drier, the condensation efficiency class in accordance with point 2 of Annex VI, expressed as 'condensation efficiency class 'X' on a scale from G (least efficient) to A (most efficient)'; this may be expressed by other means provided it is clear that the scale is from G (least efficient) to A (most efficient);

o. if the household tumble drier is a condenser tumble drier, the average condensation efficiency Cdry and C dry½ of the standard cotton programme at full load and partial load and the weighted condensation efficiency (Ct) for the 'standard cotton programme at full and partial load', as a percentage and rounded to the nearest whole percent;

p. the sound power level (weighted average value — LWA) expressed in dB and rounded to the nearest integer for the standard cotton programme at full load;

q. if the household tumble drier is intended to be built-in, an indication to this effect.

2) One product fiche may cover a number of household tumble drier models supplied by the same supplier. The information contained in the fiche may be

given in the form of a copy of the label, either in colour or in black and white. Where this is the case, the information listed in point 1 not already displayed on the label shall also be provided.

Information to be provided in cases where end-users cannot be expected to see the tumble drier displayed:

1. The information referred to in Article 4(b) shall be provided in the following order:
   a. the rated capacity in kg of cotton, for the standard cotton programme at full load;
   b. whether the household tumble drier is an air-vented, condenser or gas-fired household tumble drier;
   c. the energy efficiency class as defined in point 1 of Annex VI;
   d. for electric mains-operated household tumble drier:
      the weighted Annual Energy Consumption (AEc) rounded up to the nearest integer, to be described as: 'Energy consumption "X" kWh per year, based on 160 drying cycles of the standard cotton programmes at full and partial load, and the consumption of the low-power modes. Actual energy consumption per cycle will depend on how the appliance is used.';

      for household gas-fired tumble drier:
      the weighted Annual Energy Consumption (AEC(Gas)) rounded up to one decimal place; it shall be described as: 'Energy consumption "X" kWh-Gas per year, based on 160 drying cycles of the standard cotton programme at full and partial load. Actual energy consumption per cycle will depend on how the appliance is used'; and the weighted Annual Energy Consumption (AEC(Gas)el) rounded up to one decimal place; it shall be described as: 'Energy consumption "X" kWh per year, based on 160 drying cycles of the standard cotton programme at full and partial load, and the consumption of the low-power modes. Actual energy consumption per cycle will depend on how the appliance is used'
   e. whether the household tumble drier is an 'automatic tumble drier' or 'non-automatic tumble drier'
   f. the energy consumption (Edry, Edry½ , Egdry , Egdry½ , Egdry,a, Egdry½,a) of the standard cotton programme at full and partial load, rounded up to two decimal places and calculated in accordance with Annex VII;
   g. g) the power consumption of the off-mode (Po) and the left-on mode (Pl) for the standard cotton programme at full load;

h. (h) the programme time of the 'standard cotton programme at full load' (Tdry) and the programme time of the 'standard cotton programme at partial load' (Tdry½), in minutes and rounded to the nearest minute, calculated in accordance with Annex VII;
i. (i) if the household tumble drier is a condenser tumble drier, the condensation efficiency class in accordance with point 2 of Annex VI;
j. (j) the sound power level (weighted average value — LWA) for the standard cotton programme at full load, expressed in dB and rounded to the nearest integer; (k) if the household tumble drier is intended to be built-in, an indication to this effect.

2. Where other information contained in the product fiche is also provided, it shall be in the form and order specified in Annex II.
3. The size and font in which all the information referred in this Annex is printed or shown shall be legible.

Commission Delegated Regulation (EU) No 2017/254[49] with regard to the use of tolerances in verification procedures, replaces Annex V of Regulation 392/2012. The new Annex V specifies, that the tolerance-levels determined for the purpose of verification of compliance, are only allowed to be used by market surveillance authorities in the context of reading measurement results, rather than by producers or suppliers for the purpose of establishing values for the technical documentation or in interpreting these values with a view to achieving compliance.

Commission Regulation (EU) No 518/2014[50] with regard to labelling of energy-related products on the internet, adds a number of information requirements to Regulation 392/2012 regarding an electronic label and an electronic product fiche in cases where tumble driers are offered for sale on the internet. These include changes to Article 3 where following points are added:

- An electronic label an electronic label in the format and containing the information set out in Annex I of Regulation No 392/2012 is made available to dealers for each household tumble drier model placed on the market from 1 January 2015 with a new model identifier. It may also be made available to dealers for other household tumble drier models
- An electronic product fiche as set out in Annex II of Regulation No 392/2012 is made available to dealers for each household tumble drier model placed on the

[49] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0254&from=EN
[50] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0518&from=EN

market from 1 January 2015 with a new model identifier. It may also be made available to dealers for other household tumble drier models

Article 4, point (b) of Regulation No 392/2012 is replaced by

- Household tumble driers offered for sale, hire or hire-purchase where the end-user cannot be expected to see the product displayed, as specified in Article 7 of Directive 2010/30/EU, are marketed with the information provided by suppliers in accordance with Annex IV to this Regulation. Where the offer is made through the internet and an electronic label and an electronic product fiche have been made available in accordance with Article 3(f) and 3(g) the provisions of Annex VIII shall apply instead.

On May 9th, 2012, a **Corrigendum to Commission Delegated Regulation (EU) No 392/2012**[51] has been published. The corrigendum revises a number of dates indicated in Regulation 392/2012, but makes no substantive changes in the Regulation otherwise.

1.2.3 EU Directive 2014/35/EU – Low Voltage Directive[52]

The new Low Voltage Directive (LVD) has come into force on the 20th of April 2016. The LVD ensures that electrical equipment that operates within certain voltage limits, provides a high level of protection. The LVD Directive covers all health and safety risks of electrical equipment operating with a voltage of between 50 and 1000 volts for alternating current and between 75 and 1500 volts for direct current. Consumer goods with a voltage below 50 for alternating current or 75 for direct current are covered by the General Product Safety Directive (GPSD) (2001/95/EC).

Household appliances, hereunder tumble driers, fall under the scope of the LVD Directive.

1.2.4 EU Directive 2012/19/EU – The WEEE Directive[53]

The Waste Electrical and Electronic Equipment (WEEE) Directive implements the principle of "extended producer responsibility" where producers of EEE are expected to take responsibility for the environmental impact of their products at the end of life. As such, the WEEE Directive aims to reduce environmental impacts through setting targets for the separate collection, reuse, recovery, recycling and environmentally sound disposal of WEEE.

As EEE, tumble driers fall under the scope of the WEEE Directive. Ecodesign requirements for air conditioners and comfort fans could therefore be used to assist the WEEE Directive

[51] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0392R(01)&from=EN
[52] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0035&from=EN
[53] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0019&from=DA

aims via the introduction of product design requirements that enhance reuse, material recovery and effective recycling.

1.2.5 EU Regulation 1907/2006/EC – REACH Regulation[54]

The Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) addresses chemicals, and their safe use, and aims to improve the protection of human health and the environment through a system of Registration, Evaluation, Authorisation and Restriction of Chemicals. The REACH Regulation places greater responsibility on industry to manage the risks from the chemicals they manufacture, import and market in the EU. Companies are required to demonstrate how substances can be used safely and risk management measures must be reported to users. The REACH Regulation also establishes procedures for collecting and assessing information on the properties and hazards of substances and requires that companies register their substances in a central database. The entries in the database are then assessed to determine whether the risks of the substances can be managed. The REACH Regulation allows for some chemicals to be determined "substances of very high concern (SVHC)" due to their large potential negative impacts on human health or the environment. The European Chemicals Agency must be notified of the presence of SVHCs in certain products and the use of SVHCs may then be subject to prior authorisation. Substances can also be banned were risks are deemed to be unmanageable. As such, REACH encourages substitution of the most dangerous chemicals when suitable alternatives have been identified.

As REACH applies to all chemical substances, it also applies to chemicals that may be used in household tumble driers, for instance refrigerants in heat pump tumble driers.

1.2.6 EU Directive 2011/65/EU – RoHS Directive[55]

The Restriction of Hazardous Substances (RoHS) Directive aims to reduce hazardous substances from electrical and electronic equipment (EEE) that is placed on the EU market. A number of hazardous substances are listed in the Directive along with maximum concentration values that must be met. The RoHS Directive does contain some exemptions where it has been decided that it may not be possible to manufacture some products without the use of one or more of the banned substances.

[54] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02006R1907-20140410&from=EN
[55] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011L0065&from=EN

1.2.7 Third country national legislation - Switzerland

In Switzerland, national MEPS have been issued in 2012, banning all non-heat pump driers from the swiss market. These MEPS have been further tightened in 2015, allowing only driers classified A+ or better to remain on the market[56].

1.2.8 Voluntary agreements

ENERGY STAR[57]

In the US, the ENERGY STAR program has established requirements for clothes driers in May 2014. The criteria include requirements for energy efficiency and cycle time. Only gas, electric, and compact clothes driers meeting the ENERGY STAR definitions for an electric or gas clothes driers are eligible to earn ENERGY STAR certification in the US. In the EU, the ENERGY STAR program does not include requirements for white goods.

The following table lists the efficiency requirements made for products to be eligible to earn ENERGY STAR certification.

Table 4: US ENERGY STAR requirements for tumble driers[58].

Product type	Combined Energy Factor (kg/kWh)
Vented Gas	1.58
Ventless or Vented Electric, Standard (≥124.6 litre capacity)	1.78
Ventless or Vented Electric, Compact (120V) (<124.6 litre capacity)	1.72
Vented Electric, Compact (240V) (<124.6 litre capacity)	1.56
Ventless Electric, Compact (240V) (<124.6 litre capacity)	1.22

The Combined Energy Factor (CEF) is the quotient of the test load size, 3.83 kg for standard driers and 1.36 kg for compact driers, C, divided by the sum of the machine electric energy use during standby and operational cycles. The equation is shown here:

$$CEF = \frac{CEF\ (kg)}{E_{on} + E_{standby}}$$

The units are kg loaded clothes per kWh, the higher the value, the more efficient the clothes drier is.

Nordic Ecolabelling of White Goods

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[56] http://www.topten.eu/uploads/File/EEDAL15_Eric_Bush_Heat_Pump_Tumble_Driers.pdf
[57] https://www.energystar.gov/products/appliances/clothes_dryers/key_product_criteria
[58] Units are converted from the original version given in Imperial system to the SI-system

The Nordic Ecolabel *("Svanemærket")* uses the EU energy labelling scheme as basis for setting energy efficiency requirements for white goods including tumble driers. It covers both electric mains and gas fired household tumble driers, but not combined washer-driers or spin driers.

For a tumble drier to pass the Nordic Ecolabel requirement, numerous requirements are set:

- Energy efficiency class of at least A^+
- Condensation efficiency class of at least B
- Maximum airborne noise emission of 65dB (tested according to EN 60704)
- For heat pump driers: The refrigerants must not have a GWP_{100}>2000. For refrigerants with a GWP_{100}>100, the heat pump shall be pressure tested on the production site to prevent leakage, and it should be marked according to EN14511-4.

Furthermore, additional requirements are set for the use of chemical substances (e.g. phthalates), manufacturing processes, packaging, waste, and content of flame retardants.

1.2.9 Summary of relevant legislations

A summary of the relevant legislation that are relevant to the revision of the ecodesign and energy labelling Regulations is presented in Table 5.

Table 5: Summary of relevant legislations other than ecodesign and energy label Regulations of tumble driers

Relevant for	Name	Relevance to current review study	Aim of Regulation	Valid from	Specific relevant requirements
Ecodesign	Commission Regulation (EU) No 2016/2282	Tolerances for verification procedures in ecodesign Regulation	Amend numerous ecodesign Regulations (incl. tumble driers) with regard to the use of verification tolerances.	2016	The verification procedure in Annex III of Regulation 932/2012 is replaced by procedure in Annex XIII of Regulation 2016/2282
	Commission Regulation (EC) No 640/2009	Ecodesign efficiency requirements that may be applicable for the electric motors driving the fans and the drum in tumble driers	Set ecodesign requirements for electric motors (under revision, incl. scope of the requirements)	2009	Minimum efficiencies for electric motors related to rated power consumption
	Commission Regulation (EU) No 1275/2008 (including four amendments)	Ecodesign energy requirements for off mode and networked standby as well as power management function	Set ecodesign requirements for standby, networked standby and off modes including power management	2013	Power consumption requirements: Off mode ⩽0.5W and Networked standby ⩽3W Equipment shall offer a power management function switching

Relevant for	Name	Relevance to current review study	Aim of Regulation	Valid from	Specific relevant requirements
					equipment after the shortest period of time into off-mode
Energy labelling	Commission Delegated Regulation (EU) No 2017/254	Tolerances for verification procedures in energy labelling Regulation	Amend numerous energy label Regulations (incl. tumble driers) with regard to the use of verification tolerances	2017	The verification procedure in Annex V of Regulation 392/2012 is replaced by procedure in Annex VI of Regulation 2017/254
	Commission Regulation (EU) No 518/2014	Availability of tumble driers energy label and fiche online	Amend numerous energy label Regulations (incl. tumble driers) with regard to labelling on the internet	2014	Articles 3 and 4 of Regulation 392/2012 are amended according to article 6 of Regulation 518/2014
	EU Regulation 2017/1369	Setting a new framework for energy classes	Replace Energy labelling Directive 2010/30/EU	2017	New rules for rescaling energy classes

1.3 Review of relevant standards

1.3.1 European and international standards

European (EN) standards are documents that have been ratified by one of the three European Standards Organizations (ESOs), **CEN** (the European Committee for Standardization), **CENELEC** (the European Committee for Electrotechnical Standardization) or **ETSI** (European Telecommunications Standards Institute). Many result from the adaptation of international standards (**IEC** and **ISO**), to ensure that they are appropriate to European conditions, etc.

CEN, CENELEC and ETSI deal with different fields of activity, but cooperate in a number of areas of common interest. They also share common policies on issues where there is mutual agreement.

The CEN/CENELEC Internal Regulations, Part 2, state that the EN 'carries with it the obligation, to be implemented at national level, by being given the status of a national standard and by withdrawal of any conflicting national standards'. Therefore, a European Standard automatically becomes a national standard in each of the 34 CEN-CENELEC member countries.

The international standards mentioned in this report are **ISO** (International Organization for Standardization) standards and **IEC** (International Electrotechnical Commission) standards.

Measurement and performance standards

EN 61121:2013 *Tumble Driers for household use – methods for measuring the performance* (Modified from IEC 61121:2012)

Defines test methods for measuring performance characteristics of electric tumble driers regarding the drying performance, evenness of drying, condensation efficiency (for condenser driers), water and electric energy consumption and programme time are described in this standard. It covers household electric tumble driers, both automatic and non-automatic. Gas fired tumble driers are not covered in this standard.

The standard supersedes EN 61121:2005 which was valid during the preparatory study. The major changes include:

- Testing procedures for partial load operation (i.e. half of the maximum capacity)
- Testing procedures for power consumption in low power modes (i.e. by including a revised formula for calculating total energy consumption based on these numbers):
  - Low power modes include left-on mode and off mode
  - The left-on modes are differentiated between "unstable left-on mode" (LU) which is 30 minutes after the door has been opened post programme, and the "left on mode" (LO) which starts after the LU has finished.
- Standardised control procedures for market surveillance authorities for checking measured values in comparison to values declared by the manufacturer under consideration of permitted tolerances cf. Regulation No 392/2012 are updated.

The energy consumption during use is calculated based on 7 runs where 3 is with full capacity, and 4 is with partial load. The annual energy consumption (AEc) is based on the energy consumption during use, and its power consumption in off modes, as follows:

$$AE_c = E_t \times 160 + \left\{\frac{P_o + P_{LO}}{1.000} \times \left[\frac{525600 - (t_t + t_{mLU}) \times 160}{2 \times 60}\right]\right\} + \left(\frac{P_{LU}}{1.000} \times \frac{t_{mLU} \times 160}{60}\right)$$

With

E_t being the average total energy consumption of the active mode, **P_{LU} / P_{LO}** being the power consumption doing the left-on modes, **P_O** being the power consumption in off-modes, **t_t** being the programme time, **t_{mLU}** being the time of the LU left-on mode, and **160** is the number of standard drying cycles per year.

The first part of the equation is hence the energy consumption of 160 drying cycles, and the rest is the power consumption of the left-on and off-modes.

This is slightly different from the AE_c calculation in Regulation No 392/2012, which doesn't differentiate between the left on modes. The more recent AE_c calculation method, in comparison to what defined in the Ecodesign and Energy Labelling Regulations for tumble driers, results in lower AE_c for driers with power management systems that automatically switches the tumble drier to off-mode post cycle. However, it is the method in the Regulations which is used to calculate the AEc for Ecodesign and Energy Labelling purposes.

The energy efficiency index (EEI) is defined as the ratio of the annual energy consumption, and the standard annual energy consumption (SAEc):

$$EEI = \frac{AEc}{SAEc} \times 100$$

With SAEc for condenser driers in kWh/year being defined as

$$SAEc = 140 \times c^{0.8} \frac{kg}{cycle}$$

With **c** being the rated capacity for the cotton drying program. 140 is an arbitrary factor.

For vented driers, a correction factor for the lost energy in the vented air, is added as

$$SAEc = 140 \times c^{0.8} - 30 \times \frac{t_t}{60}$$

With $\mathbf{t_t}$ being the cycle time in minutes.

The testing sequence is generally very thorough, and the overall procedure is to run a drying sequence until 5 valid runs are achieved. The mean value of these runs is then used as the final figure. The validity of the sequence is based on the final moisture content in laundry. The laundry used is cotton with 60% humidity, and the final moisture level is either 0% (bone dry), 12% (iron ready), or 2% (Synthetic/blends textiles). The programme used is determined before the test series. The selected programme is used for all 5 testing runs. If the target moisture content is outside the allowable tolerances, a new programme is chosen, and the testing series is restarted. The new programme is chosen based on trial-and-error, depending on what type of programme can reach the desired moisture content the best.

There are no restraints on time consumption or the amount of wear on the laundry during the drying cycle.

One major item to note, is the water quality used for wetting the laundry. Automatic tumble driers, which is units that stop after a certain amount of moisture content in the load is reached, are very dependent on the water quality used for testing. This is because the sensors used to measure the moisture content in the laundry are dependent on the conductivity of the fabric, which can be influenced by the water hardness, alkalinity, and pH level. The water is treated according to IEC 60734:2012, which makes sure that the water used in all household appliances are of equal standard, but it may not reflect the everyday user setup. If the automatic tumble driers are used where water properties differ by a large extent from the reference values, the driers may not be able to stop drying even though the desired moisture content is reached. This can lead to increased energy consumption or undesired drying results. The manufactures can hence optimize their units for reference water properties, without considering the effect on the "real" water quality throughout the EU.

Recent developments of standardisation work by TC59X/SWG1.9 on EN 61121:2013

The ongoing standardisation work proposes numerous changes to the standard with varying extend. The major changes proposed by the working group as of November 2017 includes:

- A need for a more precise verification procedure than given in the Regulation.
- Definition of "combined test series" to be added.
- A revised calculation method for condensation efficiency
    - Currently measurement overrepresents partial load, and underrepresents full loads → From weighted average, to a summation of whole test series

EN 1458-2:2012 *Domestic gas fired tumble driers of types B22D and B23D, of nominal heat input not exceeding 6 kW – Part 2: rational use of energy*

Part 2 of this standard specifies the requirements and test methods for rational use of energy for domestic gas fired tumble driers of types B22D and B23D of nominal heat input not exceeding 6 kW.

The tumble drier shall have a gas energy consumption not exceeding 1.11 kWh/kg of standard load.

The electrical energy consumption is measured in accordance with EN 61121. The gas energy consumption E_g is determined in kWh as

$$E_g = 0.278V_c \times H_s$$

With V_c being the volume of dry gas consumed, and H_s being the gross calorific value of the dry gas under reference conditions (15°C and 1013.25 mbar). The volume of gas is measured with a gas meter.

In Regulation No 392/2012, this energy consumption is then divided by a factor of 2.5 (in order to convert between the value of primary and electric energy) and added the auxiliary electric consumption, in order to give the weighted energy consumption E_t, used in the calculation of the EEI.

EN 60704-2-6:2012 (IEC 60704-2-6:2012) ***Household and similar electrical appliances – Test code for the determination of airborne acoustical noise – Part 2-6: Particular requirements for tumble driers***

Defines methods of determination of airborne acoustical noise. Part 1 states general requirements, Part 2-6 specifies particular requirements for tumble driers, Part 3 defines the procedure for determining and verifying declared noise emission values. This harmonised standard constitutes the method for measuring sound power level in Regulation 392/2012[59].

EN 50564:2011 (IEC 62301-1:2011) ***Electrical and electronic household and office equipment. Measurement of low power consumption***

Defines methods for measuring the electrical power consumption in standby mode. Applicable to mains powered electrical household appliances and to the mains powered parts of appliances that use other fuels such as gas or oil.

Safety standards

EN 1458-1: 2012 ***Domestic gas fired tumble driers of types B_{22D} and B_{23D}, of nominal heat input not exceeding 6 kW***

Part 1 of this standard specifies safety requirements for domestic gas fired tumble driers of types B_{22D} and B_{23D} of nominal heat input not exceeding 6 kW.

EN 60335-1:2012+A11:2014 (IEC 60335-1:2010+A1:2013+A2:2016) ***Household and similar electrical appliances – Safety.***

Part 1 of this standard states general safety requirements. Parts 2-11 specify requirements for tumble driers intended for household and similar purposes. Parts 2-43 deal with the safety of electric clothes driers for drying textiles on racks located in a warm airflow and to electric towel rails, for household and similar purposes, with rated voltage not exceeding 250V. Parts 2-102 specify requirements for gas, oil and solid-fuel burning appliances having electrical connections.

Substances, materials and end-of-life standards

ISO 11469:2016 ***Plastics - Generic identification and marking of plastics products***

Specifies a system of uniform plastic material marking. The standard does not cover every aspect of marking (e.g. the marking process, the minimum size of the item to be marked, the size of the lettering or the appropriate location of the marking), but the marking system described is intended to help identify plastics products for subsequent decisions concerning handling, waste recovery or disposal. The standard refers to ISO 1043-1 for generic identification of the plastics.

[59] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014XC0516(03)&from=EN

EN ISO 1043-2:2011 ***Plastics - Symbols and abbreviated terms. Fillers and reinforcing materials***

Defines abbreviated terms for the basic polymers used in plastics, symbols for components of these terms, and symbols for special characteristics of plastics.

IEC TR 62635:2012 ***Guidelines for end-of-life information provided by manufacturers and recyclers and for recyclability rate calculation of electrical and electronic equipment***

IEC/TR 62635:2012(E) provides a methodology for information exchange involving electronic and electrical equipment manufacturers and recyclers. The standard also provides a methodology enabling calculation of the recyclability and recoverability rates of to facilitate optimized end of life treatment operations.

EN 50419:2006 ***Marking of electrical and electronic equipment in accordance with Article 11(2) of Directive 2002/96/EC (WEEE)***

Product marking requirements needed to ensure compliance with the WEEE Directive and additional information relating to the marking requirements, including positioning, visibility, dimensions, location and referenced documents. The marking requirements are applicable to all manufacturers and producers of electrical and electronic equipment placing products on the EU market.

EN 50625-1:2014 ***Collection, logistics & treatment requirements for WEEE - Part 1: General treatment requirements***

Part of a series of standards requested in Commission Mandate M/518 which aim to support implementation and effectiveness of Directive 2012/19/EU (WEEE). The standard contains requirements applicable to the treatment of all types of WEEE and addresses all operators involved in the treatment (including related handling, sorting, and storage) of WEEE. In particular, the standard addresses the following issue areas:

- Management principles
  - Technical and infrastructural pre-conditions
  - Training
  - Monitoring
  - Shipments
- Technical requirements
  - General
  - Receiving of WEEE at treatment facility
  - Handling of WEEE
  - Storage of WEEE prior to treatment
  - De-pollution (including Annex A normative requirements)

- De-pollution monitoring (including Annex B normative requirements)
- Treatment of non-depolluted WEEE and fractions
- Storage of fractions
- Recycling and recovery targets (including Annex C & D normative requirements)
- Recovery and disposal of fractions

- Documentation

The standard applies to the treatment of WEEE until end-of-waste status is fulfilled, or until the WEEE is prepared for re-use, recycled, recovered, or final disposal.

EN 62321 series *Determination of certain substances in electrotechnical products*
The purpose of the harmonized EN 62321/IEC 62321 series of standards is to provide test methods that will allow determination of the levels of certain substances of concern in electrotechnical products on a consistent global basis.

EN 50581:2012 *Technical documentation for the evaluation of electrical and electronic products with respect to restriction of hazardous substances*
The EN 50581 standard specifies the technical documentation a producer of EEE has to collect for applicable substance restrictions in order to demonstrate compliance with Directive 2011/65/EU (RoHS). The technical documentation required to meet the standard includes:

- A general product description
- Documentation of materials, parts and/or sub-assemblies
- Information showing the relationship between the technical documents and respective materials, parts and/or sub-assemblies
- A list of harmonized standards and/or technical specifications used to prepare the technical documents.

Other standards

EN 61000 (IEC 61000) *Electro Magnetic Compatibility (EMC) standards*
Deals with different aspects regarding electro-magnetic compatibility and sets the basis for the European EMC legislation. Part 1 states general considerations, part 2 describes and classifies the environment and specifies compatibility levels, part 3 specifies emission and immunity limits, part 4 defines testing and measurement techniques, part 5 defines installation and mitigation guidelines and part 6 defines generic standards.

EN 62233:2008 *Measurement methods for electromagnetic fields of household appliances and similar apparatus with regard to human exposure*

Seeks to limit the electro-magnetic fields (EMF) produced by electrical household appliances in order to protect human beings.

IEC 62430:2009 *Environmentally conscious design (ECD) for electrical and electronic products and systems*

Specifies requirements and procedures to specify generic procedures to integrate environmental aspects into design and development processes of electrical and electronic products including combination of products, and the materials and components of which they are composed.

1.3.2 Mandates issued by the EC to the European Standardization Organizations

M/544 – Standardisation mandate to the European standardisation organisations as regards ecodesign requirements for networked standby in support of Regulation (EC) No 1275/2008 and Regulation (EC) No 642/2009

This mandate allows the introduction of network standby in a future revision of the standard EN50564:2011 – Electrical and electronic household and office equipment - Measurement of low power consumption.

If networked standby is to be taken into account then tumble driers fit the definition of edge equipment in the draft version prEN 50643, which is: "networked equipment that can be connected to a network and interact with that network or other equipment and that does not have, as its primary function, the passing of network traffic to provide a network."

Regarding networked standby there are some useful definitions in Regulation (EC) No 1275/2008[60]:

Network means a communication infrastructure with a topology of links, an architecture, including the physical components, organisational principles, communication procedures and formats (protocols).

Networked equipment means equipment that can connect to a network and has one or more network ports.

Networked standby means a condition in which the equipment is able to resume a function by way of a remotely initiated trigger from a network connection.

M/543 – Material Efficiency

[60] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008R1275-20170109&from=EN

In December 2015, the EC published a standardisation request to the ESOs covering ecodesign requirements on material efficiency aspects for energy-related products in support of the implementation of Directive 2009/125/EC.[61] It was noted in the mandate, that the absence of adequate metrics is one of the reasons for the relative lack of ecodesign requirements related to material efficiency in previous ecodesign implementing measures. The mandate therefore requests that the ESOs draft new European standards and European standardisation deliverables on material efficiency aspects for energy-related products in support of the ecodesign Directive 2009/125/EC. This standardisation request clarifies that the following material efficiency aspects should be covered:

- Extending product lifetime.
- Ability to re-use components or recycle materials from products at end-of-life.
- Use of re-used components and/or recycled materials in products

1.3.3 Summary of relevant standards

A summary of the relevant standards to the reviewed ecodesign and energy labelling Regulations is presented in Table 6.

Table 6: Summary of relevant standards for ecodesign and energy labelling Regulations

Name	Relevance to current review study	Aim of standard	Valid from	Replacing / Expanding standard
EN 61121:2013	Yes	Methods for measuring the performance of electric mains TDs	2013	Supersedes EN 61121:2005
EN 1458-2:2012	Yes	Methods for measuring performance for gas-fired TDs	2012	Supersedes EN 1458-2:2001
EN 60704-2-6:2012 (IEC 60704-2-6:2012)	Yes	Methods for determining airborne acoustical noises for TDs	2012	No
EN 50564:2011 (IEC 62301-1:2011)	Yes	Methods for measuring energy consumption in standby modes (Both electric and gas fired)	2011	No
EN 1458-1: 2012	Yes	Safety requirements for gas fired tumble driers	2012	No
EN 60335-1:2012+A11:2014 (IEC 60335-1:2010+A1:2013+A2:2016)	No	General safety requirements for electric connections in appliances.	2012 /2014	No
ISO 11469:2016	No	General identification and marking of plastic products	2016	No
EN ISO 1043-2:2011	No	Defines abbreviated terms and symbols for basic polymers used in components	2011	No

[61] http://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=564

Name	Relevance to current review study	Aim of standard	Valid from	Replacing / Expanding standard
IEC TR 62635:2012	Yes	Guidelines for end-of-life information provided by manufactures/recyclers.	2012	No
EN 50419:2006	No	Marking of electrical and electronic equipment	2006	No
EN 50625-1:2014	Yes	Implementation and effectiveness of WEEE	2014	No
EN 62321	No	Test methods for determining levels of certain substances in electrotechnical products		No
EN 50581:2012	No	Evaluation of electrical and electronic products regarding hazardous substances.	2012	No
EN 61000 (IEC 61000)	No	Electromagnetic compatibility standards		No
EN 62233:2008	No	Measurement methods for EMF produced by household appliances	2008	No
IEC 62430:2009	No	ECD for electrical systems	2009	No

1.4 Review of relevant legislation, standards and voluntary agreements on resource efficiency

Within the past 10 years the awareness of resource depletion has increased, and the ideas of circular economy have been widely accepted as a solution that can improve the resource efficiency. The European commission published in 2015 a circular economy package that included an action plan to promote circular economy[62]. The areas of actions that are most relevant in connection with ecodesign is the general measures on product design.

Product design is key to facilitating recycling, repair and refurbishment, but also more durable products. All measures hold the potential to reduce the consumption of virgin materials (including critical raw materials) and reduce the environmental burden of products.

To reach better design of products the Commission will:

- *"Support repairability, durability, and recyclability of products in product requirements under the Ecodesign Directive, taking into account specific requirements of different products. The Ecodesign working plan 2015–2017 will identify product groups that will be examined to propose possible eco-design and/or energy labelling requirements. It will set out how ecodesign can contribute to the objectives of the circular economy. As a first step, the Commission will propose*

[62] https://ec.europa.eu/growth/industry/sustainability/circular-economy_en

requirements for electronic displays, including requirements related to material efficiency."

- *"Propose the differentiation of financial contributions paid by producers under the Extended Producer Responsibility scheme on the basis of the end-of-life management costs of their products. This provision under the revised legislative proposal on waste creates economic incentives for the design of products that can be more easily recycled or reused."*
- *"Examine options and actions for a more coherent policy framework for the different strands of work on EU product policy in their contribution to the circular economy."*

Besides the economy work package there is also a number of relevant legislations, standards and voluntary agreements on resource efficiency, which are briefly described below.

The Spanish Royal Decree (No 110/2015)[63] has a set of requirements regarding the amount of collected WEEE that should be prepared for reuse. The requirements are e.g.:

- 2017 - 2 % of large household appliances collected as WEEE and 3 % of IT equipment collected as WEEE is to be prepared for reuse
- 2018 - 3 % of large household appliances collected as WEEE and 4 % of IT equipment collected as WEEE is to be prepared for reuse
- Improve the monitoring, traceability and supervision requirements of waste
- management activities by the public administration.
- Separate collection, transport and storage conditions to allow appropriate
- preparation for re-use and to prevent breakages and loss of materials
- Recognise the role of social-economy actors in waste collection and treatment and the possibility of handing over WEEE to these entities.

M/543 – Material Efficiency

In December 2015, the European Commission published a standardisation request to the ESOs covering ecodesign requirements on material efficiency aspects for energy-related products in support of the implementation of Directive 2009/125/EC.[64] It was noted in the mandate, that the absence of adequate metrics is one of the reasons for the relative lack of ecodesign requirements related to material efficiency in previous ecodesign implementing measures. The mandate therefore requests that the ESOs draft new

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[63]http://www.mapama.gob.es/es/calidad-y-evaluacion-ambiental/temas/prevencion-y-gestion-residuos/spanishlegislationonwasteofelectricandelectronicequipmentsweeeroyaldecree1102015of20february_tcm7-382140.pdf

[64] http://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=564

European standards and European standardisation deliverables on material efficiency aspects for energy-related products in support of the ecodesign Directive 2009/125/EC. This standardisation request clarifies that the following material efficiency aspects should be covered:

- Extending product lifetime.
- Ability to re-use components or recycle materials from products at end-of-life.
- Use of re-used components and/or recycled materials in products

prEN 45558

This European Standard is currently under development. The aim of the standard is to develop a method so information on critical raw materials can be exchanged up and down in the supply chain of energy related products. Though, it does not provide any specific method to capture this information. How organisations will capture the data is individually which allow more flexibility.
The standard e.g. allows organisations to

- to assess the use of critical raw materials in energy related products
- to support collection and recycling processes, so the critical raw materials can be extracted End-of-Life
- to use information on critical raw materials in life-cycle management

Furthermore, this standard can support policy makers regarding policy around the or import of critical raw materials. It can also prove to be valuable in connection with Ecodesign studies as more information about the materials are available. This can lead to more precise estimations of both the value and impact of critical raw materials in energy related products, but also measures that can improve the recycling of critical raw materials.

prEN 45554

This European Standard is currently under development and deals with the assessment regarding the ability to remanufacture energy related products. The aim is to ensure a general method for assessing the ability to remanufacture energy related products. The aspects considered are among others:

- Assessment of accessibility (Including a formula that can evaluate the accessibility)
- Assessment of the ability to re-/disassemble (Including disassembly sequence, disassembly index, time for disassembly and different formulas)

This standard may allow requirements regarding disassembly in ecodesign as this standard creates a common framework for documenting the disassembly. Without any standard it is difficult for the market surveillance authorities to control such measures.

prEN 45556

This European Standard is currently under development. The aim is to ensure a general method for assessing the proportion of reused components in energy related products. The aspects considered are among others:

- Calculation of reused component index
- Quality assurance (maintain records of previous quality control)
- Marking and Instructions (e.g. ensure traceability of the reused component)

prEN 45557

This European Standard is currently under development. The aim is to ensure a general method for assessing the proportion of recycled material content in energy related products. This standard relates to the physical characteristic of the materials and manufacturing history of all the parts in the product. The standard includes:

- Methods for calculating the recycled material content
- Specific guidelines per material type
- Traceability
- Reporting

Guidelines for accounting and reporting recycled content will contribute to avoid potentially unsubstantiated and misleading claims on recycled content for which it is not clear how they are determined. This standard enables requirements of recycled content in products as these claims can be controlled by market surveillance authorities

prEN 45555

This European Standard is currently under development and deals with methods for assessing the recyclability and recoverability of energy-related products. This standard suggests a horizontal approach for all energy related products. However, the standard also states that a correct assessment can only be done in a product-specific way, taking into account specific parameters of a specific product group. This standard defines a series of parameters which may be considered to calculate product specific recycling and recoverability rates.

The standard provides a general methodology for:

- Assessing the recyclability of energy related products
- Assessing the recoverability of energy related products

- Assessing the ability to access or remove certain components of interest to facilitate better recycling and recovery operations.
- Assessing the recyclability of critical raw materials from energy related

prEN 45555

This European Standard is currently under development and deals with methods for the assessment of the ability to repair, reuse and upgrade energy related products. This standard suggests a horizontal approach for all energy related products. The standard is described as generic and general in nature which means that it is not intended to be applied directly but may be cited in relation with product specific or product group harmonised standards.

The standard provides a general methodology for:

- the ability to repair products
- the ability to reuse products, or parts thereof,
- the ability to upgrade products, excluding remanufacturing.

Furthermore, this standard provides a common framework for future vertical/product specific standards.

Standard prEN 50614

This European Standard is currently under development (within the standardisation mandate M/518). The purpose of the standard is to facilitate the preparation for re-use of equipment and support the WEEE Directive. The standards include measures on how to check, clean or perform repair recovery operations, so components of discarded products (waste) are prepared so they can be reused without any other pre-processing. The standard also provides relevant description of quality, safety and environmental requirements that a reuse operator should adopt to ensure safe products for the consumer and also to protect the brand of the product (avoid faulty and dangerous remanufactured products) as consumers still may connect a remanufactured product with the brand of the appliances which not necessarily is the case.

Standard BS 8887-211

This standard focus on design for manufacture, assembly, disassembly and end-of-life processing (MADE) of computing hardware. So, this standard is not related to household appliances but some of the requirements could be used across all electronic products. The standard describes the different types of products that potentially could re-enter the production. Examples of products that can re-enters the production are:

- Non-working products (out-of-the-box)
- Products that needs repair within the warranty period (returned to the OEM)

- Unsold products (factory overstock, demonstration models, "try before buy – offer"
- Return of used products (e.g. lease or "trade-in-offers" – relevant in connection with circular economy)

Standard VDI 2343

This standard is providing a common framework for the different definitions on reuse which is crucial to reach a common understanding on the different definitions. Definitions are also crucial in connection with interpretation of Regulation and without any clear definitions any requirements towards reuse/remanufacturing/refurbishment will be invalidated. In general, refurbishment is not clearly defined in most EU Regulation (e.g. fully refurbishment is defined in the Regulation on medical devices[65]). The standard defines different levels of reuse such as:

- Repair – restores defective product
- Refurbishing – restores used product to a certain quality
- Remanufacturing – restores used product to 'as good as new' through new and reconditioned components and parts;
- Upgrading – improving the functions/properties of the original product

Definitions are very important in connection with the liability of the product. At which level of repair/reuse is the original manufacturer (brand on the appliance) responsible for the product.

Standard ONR 192102

Standard ONR 192102 is an Austrian standard that establishes a label for electronic products designed for easy repair.

The standard/label established both obligatory requirements that should be followed by anyone claiming the label, but also a set of voluntary requirements. If the also follow the voluntary criteria they are awarded with a score. The score is dependent on the number of

[65] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2017:117:FULL&from=EN

criteria the product complies with and an overall reparability score is awarded which are either 'good', 'very good' or 'excellent'.

- Examples of the requirements and criteria are:
- Information relevant for disassembly (e.g. instructions, break down plan)
- Requirements on information for repair (e.g. instructions and exploded views)
- Easiness of disassemble (e.g. possibility of breaking down the product and accessibility to inner parts (cable lengths, space for mounting, welding, screw orientation and size, scale of design)

Such standards and labels are very important for both manufactures designing products for the circular economy, but also regarding requirements. European standard can be developed in line with ONR 192102, which makes any requirements towards improvement resource efficiency (design for easy disassemble etc.) more robust and makes it possible for the market surveillance authorities to control such requirements.

2. Market and stock

2.1 Sales

The MEErP recommends using Eurostat data on production (PRODCOM), and calculate the EU sales and trade as "EU Production + EU import – EU export". However, experience form other studies and also the MEErP guidance document itself, finds the PRODCOM data not very reliable for the analysis of individual products. This also applies to tumble driers, especially for the NACE rev. 2.0, since the PRODCOM categories have a broader scope than the Regulations and the data therefore cannot be used directly to represent the market of products in scope of the Regulations or the study. As the PRODCOM data is still the official source for EU policies, the sales and trade data were collected from the database and shown in this task, but the GfK data will be used for all further calculations and analyses.

The sales volumes of tumble driers within the EU is therefore based on purchased market data from the large international market research institute GfK, who provided point of sales tracking data on tumble driers for 21 countries (see Annex I). The sales and trade data for tumble driers was not available for seven of the EU-28 countries (Czech Republic, Romania, Slovenia, Slovakia, Bulgaria, Cyprus and Malta), representing a total of 9% of the EU population and 3.6% of the BNP[66]. Based on the population of these countries and their BNP, an overall EU market coverage of the GfK tumble drier data has been calculated resulting in 85%. It is therefore deemed that the GfK data provides a more accurate representation of the market than the PRODCOM data.

The GfK data were scaled to 100% for each of the 21 countries covered by GfK's data collection programme. To achieve a representation of 100% of the EU market, GfK's data were scaled up to cover the total EU market.

GfK collects point-of-sales data on different types of tumble driers, very much in line with the definitions in the Regulation. Data is available on each product type specifically, including data on all label parameters and nominal annual energy consumption for each product type. This level of detail is much higher than the data available from PRODCOM, and therefore only the overall sales are compared between GfK data and PRODCOM data in Table 7.

[66] https://europa.eu/european-union/about-eu/countries_en

Table 7: Comparison of tumble drier sales data from GfK and PRODCOM, shown as million units

Sales, millions	1995	2000	2002	2005	2006	2010	2015	2016
GfK, scaled	-	-	3.69	4.04	4.43	3.66	4.36	4.66
PRODCOM	2.53	3.50	3.60	4.71	5.56	21.05	19.36	18.97
Difference	-	-	3%	15%	23%	141%	126%	121%

As seen in Table 7, the GfK data is not available before 2002[67], which is the first year of comparison. In 2002 the data from PRODCOM was collected according to the NACE Rev 1.1 definitions[68] (see section 1.1.4), and the difference between the two datasets is 93,000 units or 3%. Also, this is the only year in the data set where the GfK data shows higher sales than the PRODCOM data, even though the difference is small. The increasing difference between the two datasets towards 2007 (end of NACE rev. 1.1), is ascribed to the increased quality of collection from Member States in the PRODCOM database, and since the product categories are broader, the PRODCOM sales data is generally higher.

From 2008 and onwards, only the NACE Rev 2.0 data is available, which means that only aggregated data for washing machines and driers (including combined washer-driers). Since the penetration rate is larger for washing machines than tumble driers, the majority of the sales are expected to be washing machines which is why the PRODCOM data deviates between 120-140% from the GfK data in the years after introduction of NACE rev 2.0.

It is clear that the data from PRODCOM after 2007 (NACE rev. 2.0) is not nearly detailed enough to be used in this study, and neither of the PRODCOM datasets offers a detail level down to different tumble drier technologies. Based on data quality and availability the GfK data is therefore used for the years where it is available (2006-2016), and the PRODCOM NACE Rev. 1.1 data is used from 1995-2005, and from 1990 to 1994 the sales are assumed to equal the 1995 sales.

Future sales are based on the yearly sales growth rates calculated from the GfK data over the last 10 years. According to these data, the average sales growth is 0.7% per year for the entire market in EU28.

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[67] 2002 and 2005 data from GfK is reported in the preparatory study
[68]Product code 29.71.13.70 "Drying machines of a dry linen capacity ≤ 10 kg"

2.1.1 Sales split and market shares

The purchased GfK data provided the sales split on different tumble drier types for the years 2013 to 2016, which corresponds to the years the ecodesign and energy labelling Regulations have been applicable. The sales data have been corrected for the countries not included in the dataset (Czech Republic, Romania, Slovenia, Slovakia, Bulgaria, Latvia, Malta) and are shown in Table 8.

Table 8: Household tumble drier sales in Europe 2013-2016, source: GfK (adjusted to EU28)

Sales, million units		2013	2014	2015	2016
Condenser	Heat pump	1.23	1.78	2.22	2.58
	Heat element	1.93	1.79	1.78	1.75
Air-vented	Heat element	0.78	0.73	0.75	0.72
	Gas-fired	0.00	0.00	0.00	0.00
Total		**3.94**	**4.30**	**4.76**	**5.08**

The data shows that the heat pump technology during the four years has become the prevalent in the EU with the market share increasing from 31% in 2013 to 51% 2016. This has been at the expense of the electric heat element tumble driers, both the condenser and the air-vented type. In 2016 the market share of heat element condenser driers was 34%, down from 49% in 2013, whereas the air-vented market share decreased from 20% to 14% in that same period. The gas tumble drier market share is in the range of 0.01-0.02% per year, corresponding to less than a thousand units per year, which is why it says zero in Table 8.

The total sales increased on average 1.6% per year from 2013 to 2016, but given the otherwise quite stable sales over the years, it is assumed that this sales growth rate will decrease towards 0% per year in 2030. Assumptions were made for the continued development of the market shares for 2025 and 2030 based on the trends seen in the market until now, with linear interpolation of market shares in the years between. This yielded the shares shown in Table 9. The 2005 market split was calculated from the preparatory study data and is assumed unchanged for all years from 1990-2005.

Table 9: Market shares of the four main tumble drier technologies

Sales, million units		2005	2010	2015	2020	2025	2030
Condenser	Heat pump	0%	9%	47%	57%	65%	80%

	Heat element	59%	64%	37%	32%	28%	20%
Air-vented	Heat element	41%	28%	16%	11%	7%	0%
	Gas-fired	0%	0%	0%	0%	0%	0%
Total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

As the preparatory study stated a very low market share of heat pump driers in 2009, the market share was assumed to be 0% in 2005, however the GfK data showed a share of 31% in 2013, and the linear interpolation for the eight years in between is therefore quite steep.

The market split shown in Table 9 together with the total market size result in the sales figures (shown as million units) in Table 10. As seen from the table, the sales of air-vented driers are expected to decrease and be very close to zero by 2030.

Table 10: Derived tumble drier sales from 1990 to 2030

Sales, million units		1990	1995	2000	2005	2010	2015	2020	2025	2030
Con-denser	Heat pump	-	-	-	-	0.34	2.22	3.05	3.60	4.46
	Heat element	3.55	3.55	3.44	2.38	2.54	1.78	1.68	1.55	1.11
Air-vented	Heat element	0.14	0.14	1.06	1.66	1.11	0.75	0.59	0.39	-
	Gas-fired	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	-
Total		**3.70**	**3.70**	**4.50**	**4.04**	**3.99**	**4.76**	**5.34**	**5.53**	**5.57**

2.1.2 Sales values

Both the PRODCOM database and the GfK database provides data on value of the EU tumble drier market, however while GfK shows the retail prices, PRODCOM shows the wholesale prices. The comparison can therefore only be made on the trends, and not on the absolute values. As PRODCOM only contains the high-level data, the comparison between the data sets will be made on the entire EU tumble drier market. The market value comparison is shown in Table 11.

Table 11: Tumble drier market values

Market values, million EUR	1995	2000	2005	2006	2010	2015	2016
GfK market value	-	-	-	1 659	1 704	2 260	2 354
PRODCOM market value	518	795	851	995	4 889	4 883	4 897

The market value according to PRODCOM has a significant increase of almost a factor 5 from 2006 to 2010, which is however not true, but is caused by the changing categorisation (from NACE V1.1 to V2.0) and the fact that the market data for washing machines and tumble driers is aggregated in one category from 2008 (see chapter 1.1.4).

Based on the sales and market values in Table 10 and Table 11, the average unit prices of tumble driers can be derived as shown in Table 12. The GfK prices are again retail prices, whereas the prices derived from PRODCOM are wholesale. There is only one year of overlap between the GfK dataset and the PRODCOM Nace 1.1 database, which is year 2006. In this specific year the mark-up factor can be estimated by dividing retail (GfK) price with the wholesale (PRODCOM) price, yielding a mark-up of 2.1. This factor should, however, be taken with caution as the sales volume differ by 23% in the two databases that year (see Table 7).

Table 12: Average unit price of tumble driers in EU

Unit prices, EUR	1995	2000	2005	2006	2010	2015	2016
GfK unit price	-	-	-	375	427	475	464
PRODCOM unit price	205	227	181	179	232	252	258

2.2 Stock

The stock of tumble driers in Europe is determined based on the sale and a normal distribution of the expected lifetime of tumble driers.

2.2.1 Lifetime

In the preparatory study, it was determined that the lifetime of tumble driers was 13 years on average, with a deviation of 1.78[69]. Other sources generally confirm this number; however, 13 years is in the high end of the reported lifetime, which ranged from 8 to 14 years[70]. According to CECED and Umwelt Bundesamt[71], the lifetime is around 12 years and it is therefore suggested to adjust the average lifetime from the preparatory value of 13 years, to 12 years with a standard variation of 2 years. This will be used for all types of tumble driers.

2.2.2 Tumble drier stock

The stock of tumble driers in the EU is calculated based on the sales figures described in chapter 2.1, and the expected lifetimes described previously, shown in Table 13.

Table 13: Average expected lifetime and assumed variations used in the stock model

Tumble drier type		Average lifetime	Standard variation
Condenser	Heat pump	12	2
	Heat element		
Air-vented	Heat element		
	Gas-fired		

Normal distribution of the lifetime was applied and multiplied with the sales volume for each tumble drier type each year, which yielded the total EU stock shown in Table 14.

Table 14: Stock of tumble driers in EU from 2000 to 2030

Stock, million units		2000	2005	2010	2015	2020	2025	2030
Condenser	Heat pump	0.00	0.00	0.44	7.27	21.18	34.89	44.61
	Heat element	37.97	38.19	31.28	26.44	23.35	21.37	18.73
Air-vented	Heat element	4.17	11.67	16.73	15.09	10.62	7.59	4.70
	Gas-fired	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Total		**42.15**	**49.89**	**48.47**	**48.82**	**55.28**	**64.00**	**68.13**

[69] Preparatory study of Ecodesign for Laundry Dryers, PriceWaterhouseCoopers, 2009.
[70] http://homeguides.sfgate.com/average-life-frontloading-drier-102084.html and https://www.mrappliance.com/expert-tips/appliance-life-guide/ and https://www.hunker.com/13410811/lifetime-of-driers and https://www.hrblock.com/tax-center/lifestyle/how-long-do-appliances-last/ and http://www.wisebread.com/this-is-how-long-these-6-appliances-should-last
[71] https://www.umweltbundesamt.de/en/publikationen/einfluss-der-nutzungsdauer-von-produkten-auf-ihre-1

When looking at the sales and the stock in a compiled graph (Figure 7), it is seen that the sales (and thus stock) increase over time, resulting in a total stock of around 68 million by 2030 compared to 50 million in 2016. With a total number of households in the EU-28 of 220 million in 2016[72], this gives a penetration rate of 23%, which is lower than the assumed penetration rate of 36% from the preparatory study[73]. The sales and stock will be used in subsequent tasks to estimate annual energy consumption.

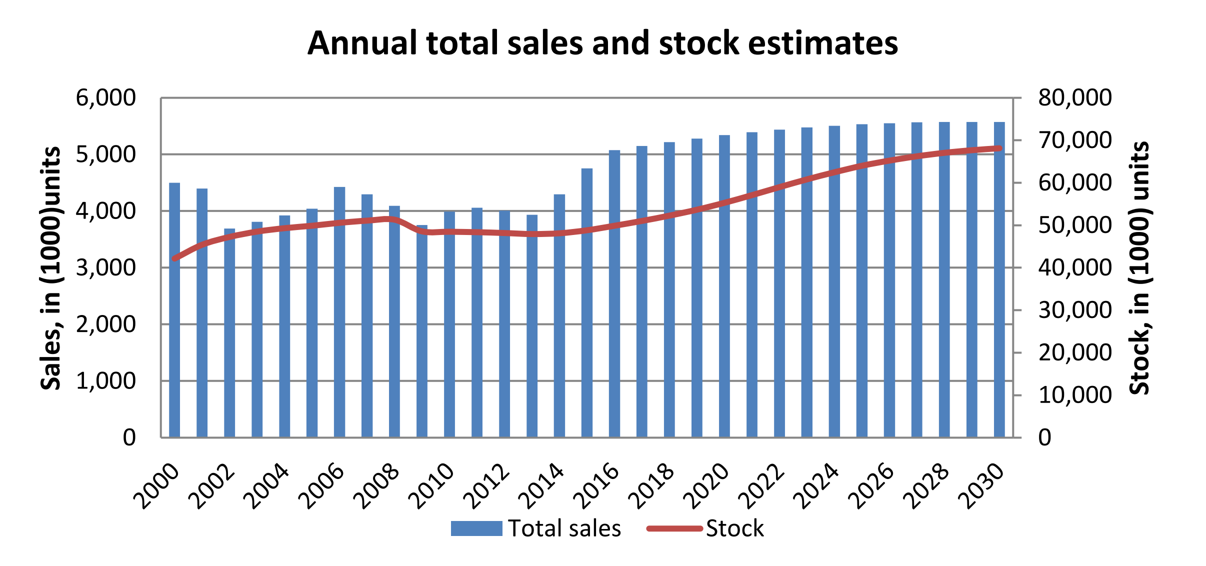

Figure 7: Annual sales and stock of tumble driers (total of all types)

2.3 Market trends

2.3.1 Sales trends

Prior to 2006, where only PRODCOM data is available, the total sales ranged between 3.5 million and 4.4 million. Even though the sales fluctuate from year to year, and overall growth rate of 1.6% p.a. from 2006 to 2016 is seen. This growth rate is expected to go linearly towards 0% until 2030.

The overall increase in sale numbers since 2010 has been dominated by heat pump tumble driers, while all other technologies have decreased in sales numbers. The gas drier sales fluctuate, but since they make up only 0.2% of total sales, this has no influence on the total market. Both the air-vented and heat element condenser driers have decreased by roughly 1 million units in sales over the last 10 years, the air-vented from 1.7 to 0.7 million units and the heat element condenser from 2.7 to 1.7 million units. In the same period the

[72] http://ec.europa.eu/eurostat/statistics-explained/index.php/Household_composition_statistics
[73] Prep study page 405

sale of heat pump condenser driers have increased from less than 100 thousand units to 2.6 million units.

2.3.2 Product trends

This section contains an analysis of the product trends since introduction of the Regulations in 2012 (Energy labelling) and 2013 (Ecodesign). The parameters included in the label are analysed in order to get an overview on the product trends. This is done based on data collected by GfK from 2013 to 2016.

Energy efficiency class

The label distribution of the different tumble drier technologies and their development over 2013 to 2016 can be seen in Figure 8, Figure 9, and Figure 10 for heat pump condenser driers, condenser driers, and air-vented driers respectively.

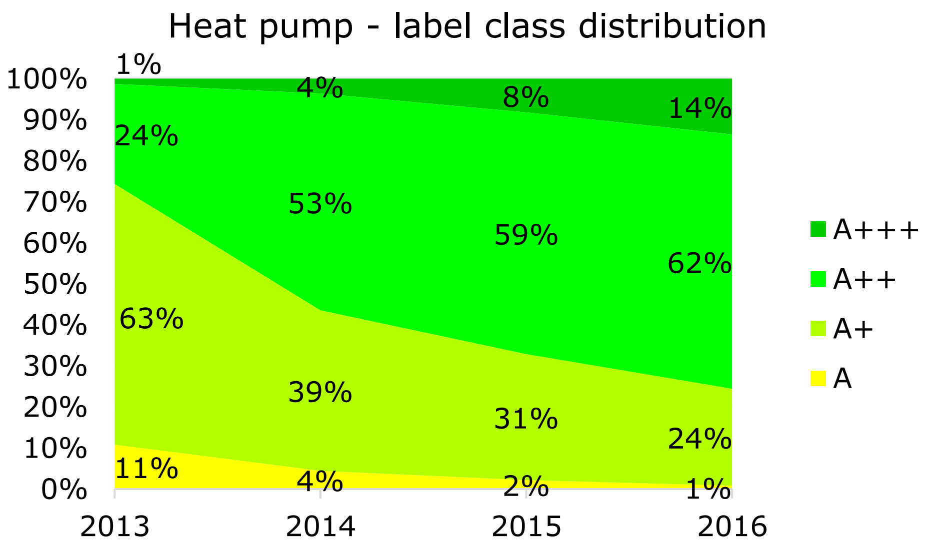

Figure 8: Energy class distribution and development for heat pump tumble driers, 2013-2016

The heat pump condenser driers covered by GfK data are all A energy class and above, with A and A+ labelled driers constituting the largest share on the market in all years. The distribution shows a shift with an increasing trend for A++ and A+++, and a decreasing trend for A and A+. The share of A+++ machines is still quite low (14%) compared to A++ (62%).

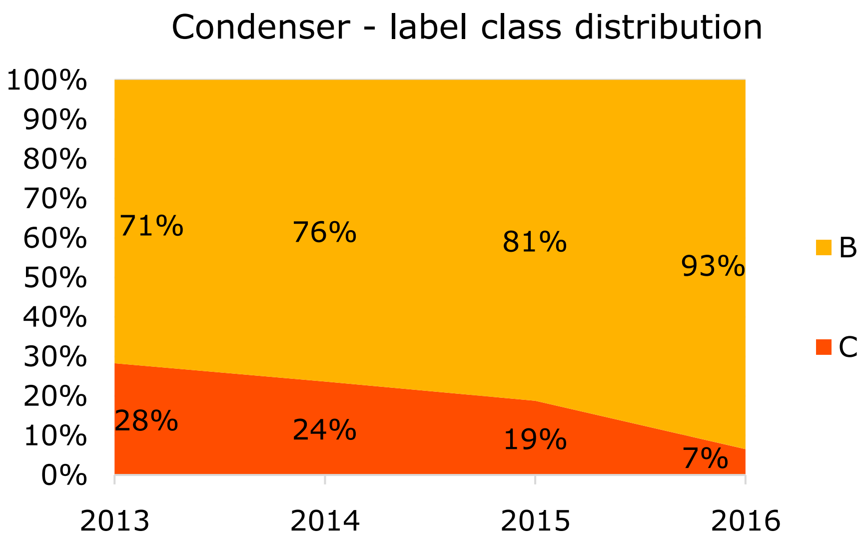

Figure 9: Energy class distribution and development for condenser tumble driers, 2013-2016

The heat element condenser driers covered by GfK data are all in the label class B or C, with B labelled driers constituting the market majority. The market dominance of B labelled driers was reinforced over the four years from 2013 to 2016, with the share increasing from 71% to 93%, and the C labelled driers simultaneously decreasing.

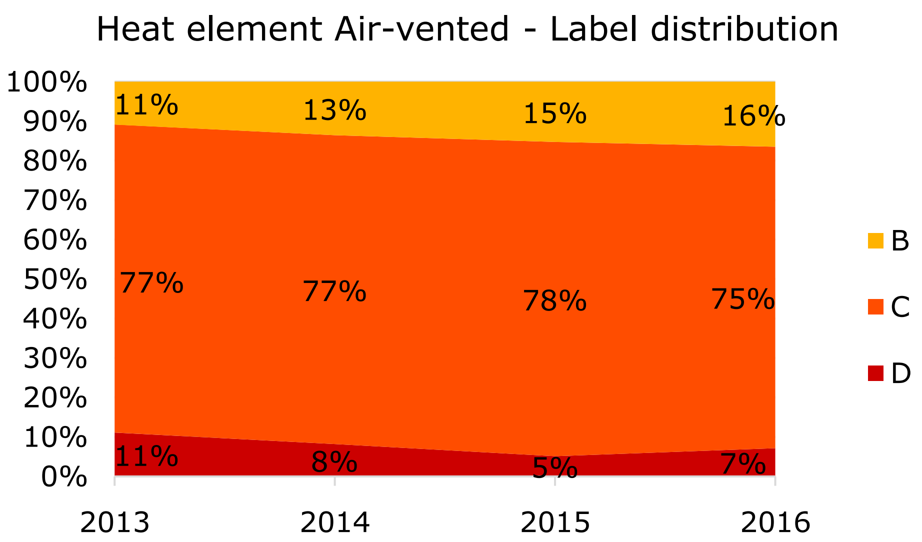

Figure 10: Energy class distribution and development for heat element air-vented tumble driers, 2013-2016

The heat element air-vented driers covered by GfK data are the least efficient in the market with energy classes ranging from B to D (the lowest on the current label). The majority (<75%) of air-vented driers are in label class C in all four years, but the share of B labelled driers has slightly increased from 2013 to 2016 from 11% to 16% at the cost of D labelled driers. The heat element air-vented driers show a smaller trend towards improved performance, in comparison to condenser driers shown in Figure 8 and Figure 9.

Data were not available for gas-fired tumble driers, but based on information from GfK, it was possible to track from a desktop research three of the models on the EU market which have 63% of the market share. Two of these three models (covering 61% of the market) feature an A+ energy class and the other features a C energy class. Gas-fired air-vented driers on the market are thus able to reach a higher energy class than the heating element air-vented drier. This might however be due to differences in the energy efficiency calculation methods between electric operated and gas-fired tumble driers.

Annual Energy consumption

Figure 11, Figure 12 and Figure 13 show distribution of the Annual Energy consumption (AE_c) for sold tumble driers during the years 2013-2016 for heat pump, condenser and heat element air-vented tumble driers respectively.

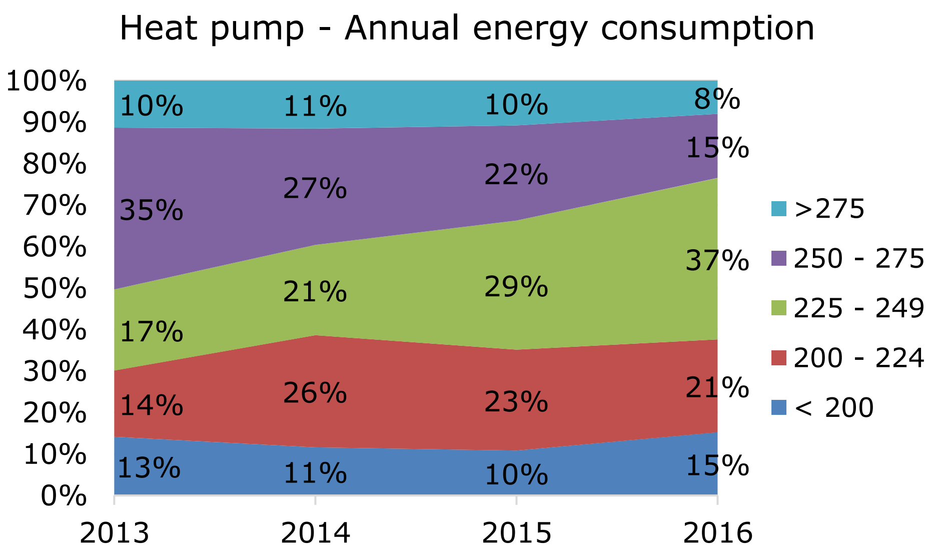

Figure 11: Distribution of annual energy consumption for the heat pump tumble driers from 2013 to 2016

The heat pump tumble drier AEc distribution shows a consistent trend with a declining weighted average AEc in the four-year period.

The three lowest intervals, '<200' and '220-225', and '225-250' kWh/year, have all made an overall increase in market share from 2013 to 2016. Oppositely, the driers in the >250 kWh/year intervals steadily decreased. The two intervals from 275 to 400 kWh/year showed no consistent trend, but the highest consuming machines above 400 kWh/year decreased and those over 500 kWh/year vanished entirely from the market.

Overall the market share of the three lowest AEC intervals (<250 kWh/year) increased from 44% to 73%, and the sales-weighted average AE_C of heat pump tumble driers decreased from approximately 246 kWh/year in 2013 to 233 kWh/year in 2016.

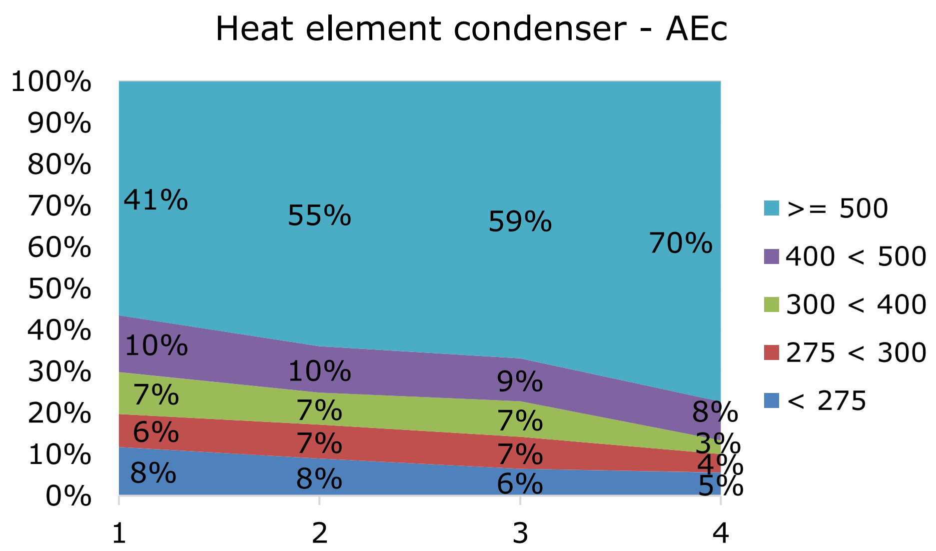

Figure 12: Distribution of annual energy consumption for heat element condenser tumble driers from 2013 to 2016

For tumble driers with heating element and condensing technology, the opposite development than for heat pumps is seen. The share of low AEC tumble driers decreased from 2013 to 2014, whereas the share of 500+ kWh/year increased.

Regarding the sales-weighted energy consumption, the data show a steady increase from 461 kWh/year in 2013 to 506 kWh/year in 2016.

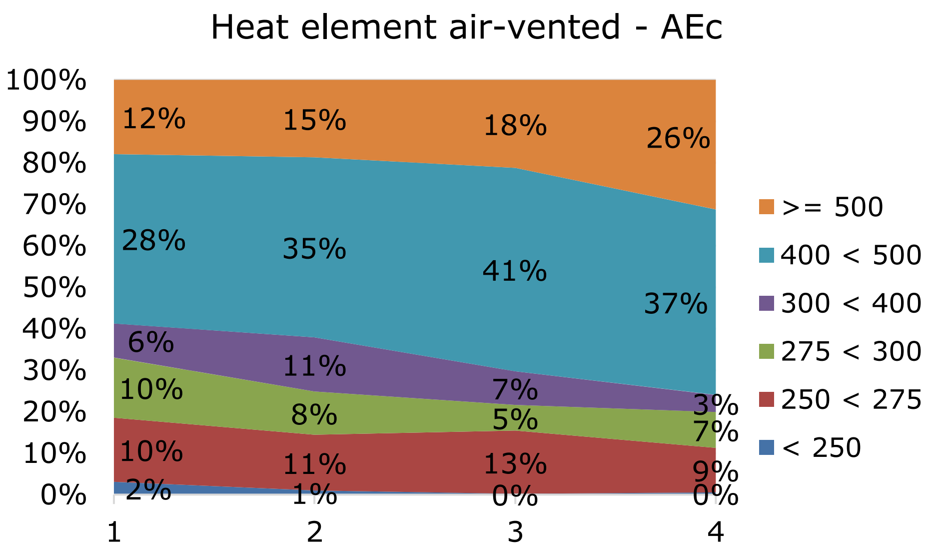

Figure 13: Distribution of annual energy consumption for heat element air-vented tumble driers from 2013 to 2016

Only very low shares of heat element air-vented driers are in the intervals <250 kWh/year. The majority is in fact in the highest consumption intervals >400 kWh/year. The share of heat element air-vented driers with AEc >500 kWh/year increased in market share. The average AEc increased from 402 kWh/year in 2013 to 436 kWh/year in 2016.

The same three models of gas-fired air-vented tumble driers were tracked in a desktop research, where the model covering 54% of the EU market consumes 256 kWh/year (in gas) by the time of the data gathering (March 2018), the other model covering 7% of the market consumes 261 kWh/year and the last consumes 459 kWh/year. The first two models have a rated capacity of 7 kg, and the last one of 6 kg.

Even though both tumble drier types equipped with heating elements showed an increase in annual energy consumption, it might not be because of a general reduction in energy efficiencies. The annual energy efficiency is calculated based on the rated capacity (see section 3.1 for details on calculating the AEc), which on average is increasing (cf. Figure 22) and is thus influencing the depicted AEc distributions. Figure 8, Figure 9, and Figure 10 show that all drier types have improved in energy efficiency from 2013 to 2016, so the increase in AEc thus originates from the increase in capacity, which is larger than the increase in energy efficiency.

Condensation efficiency

The graphs below show the market distribution of condensation efficiency classes from 2013 to 2016. Both heat pump and heat element condenser driers all have condensation efficiencies in from class C or above, showing all a minimum efficiency of 70% which is the lower limit for class C (and which is Tier 2 ecodesign requirement).

Both technologies have a high market share of products for which the condensation efficiency is not declared according to GfK data, even though this share is decreasing. This amounts to 36%/8% and 67%/45% for years 2013/2016, for heat pump driers and heating element condensing driers respectively. This is especially a problem for heat element condenser driers where the not declared market share is dominating the market. It is very unlikely that this is due to the selling out of old stocks, due to the very large stock numbers of ~27 million driers in the market from 2013 to 2016. A small portion of this could be due to wrong declaration from the retailers who the data is collected from, however since such large shares is only seen for this parameter, it seems unlikely.

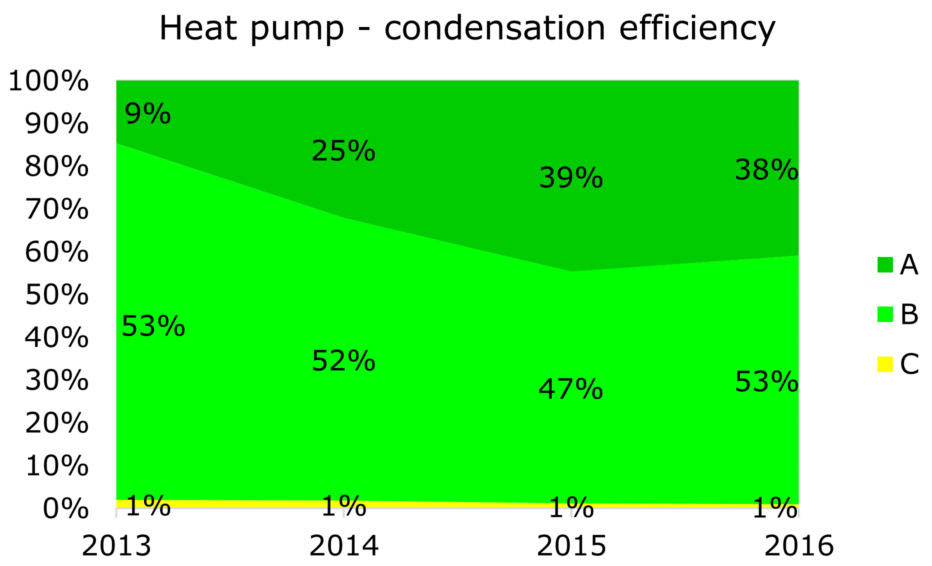

Figure 14: Condensing efficiency label class distribution for heat pump tumble driers, 2013-2016

The heat pump tumble driers are primarily class B and A. The share of A labelled products increased from 9% in 2013 to 38% in 2016, while the B labelled products declined from 53% in 2013 to 47% in 2015, but increased to 53% again in 2016. This is most likely because of the share of products that did not declare the condensation efficiency in the earlier years (decreased from 36% in 2013 to 8% in 2016), which affects the percentages. The heat pump driers with label C condensation efficiency stayed at 1% from 2013 to 2014.

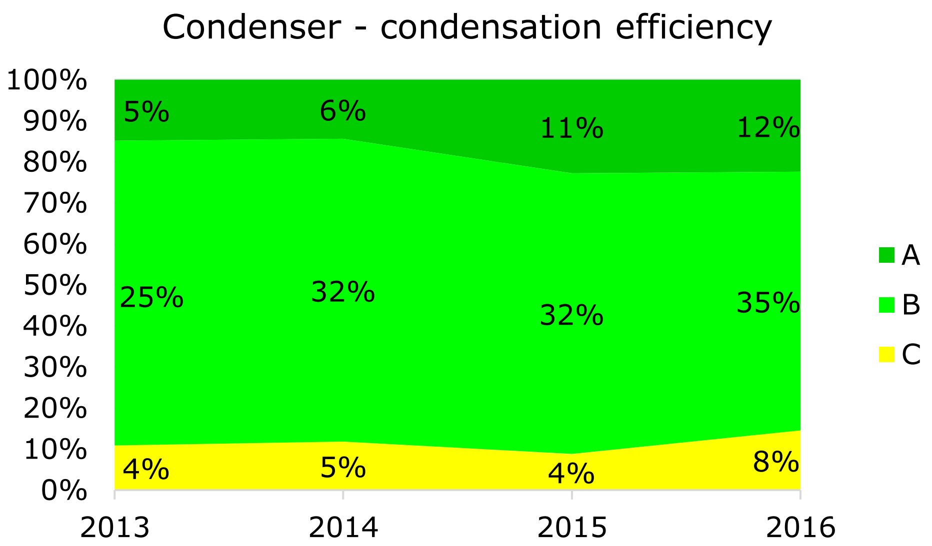

Figure 15: Condensing efficiency label class distribution for heat element condenser tumble driers, 2013-2016

For condenser driers with heat element, those with "not declared" condensation efficiency makes up the majority of the market: 67% in 2013 and 45% in 2016. When looking at the products that are in fact labelled, the largest share of the condenser drier market is class B. The share of products in class A, B and C are all increasing, but it is not certain whether this is due to a market change or the share of not declared declining.

Low power modes

Two different low power modes exist: off mode, in which the drier is effectively turned off without any kinds of displays being active, and left-on mode, which is activated when the drying cycle is complete. The power consumption is shown in Figure 16. The majority of available driers have 0W off-mode consumption, while the majority of driers have left-on mode consumption higher than 0.5W

The left-on mode duration is shown in Figure 17. Some tumble driers have no left-on mode at all, and for the majority of tumble driers the duration is below 10 minutes.

Note that Figure 16 and Figure 17 are based on the APPLiA model database[74], and not on sales data. The figures are thus showing the distributions for the models available for sale on the market, and not real sales weighted values. They are thus not representative for the EU28 market and can only be used as an indicative figure.

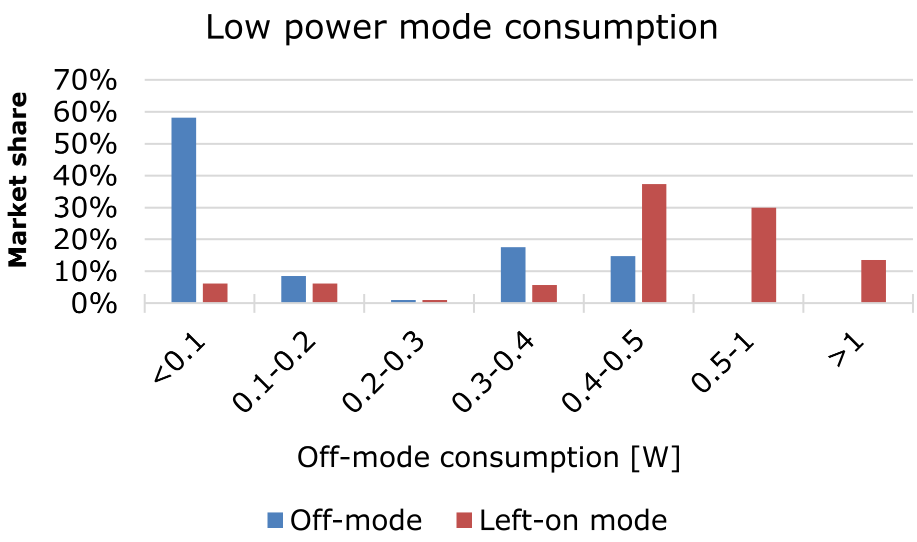

Figure 16: Power consumption in off-mode and left-mode[74]

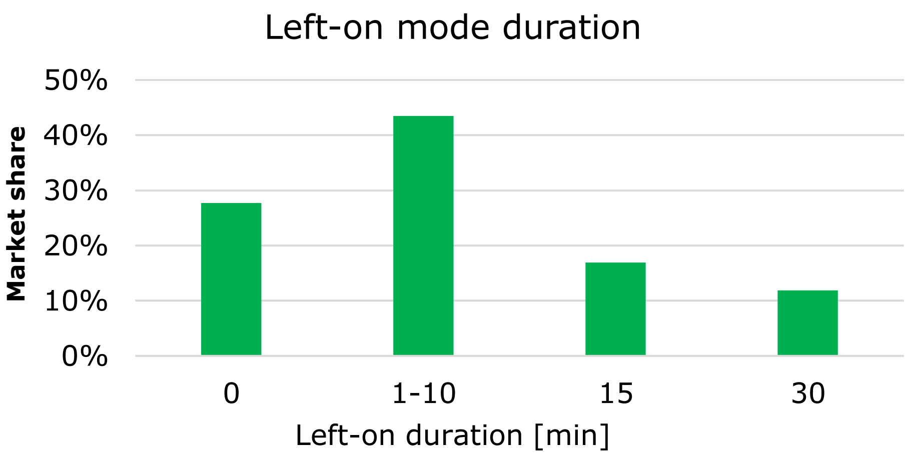

Figure 17: Left-on mode duration[74]

Rated capacity

The rated capacity is stated on the energy label and used in the EEI calculations, but there is no ecodesign requirement for this parameter. The rated capacity is the stated maximum mass in kilograms that can be dried in the tumble drier in the standard cotton programme at full load. The heat pump tumble driers which now constitute the largest share of the market, have a tendency for increasing capacity as seen in Figure 18.

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[74] *Source: APPLIA 2016 model database*

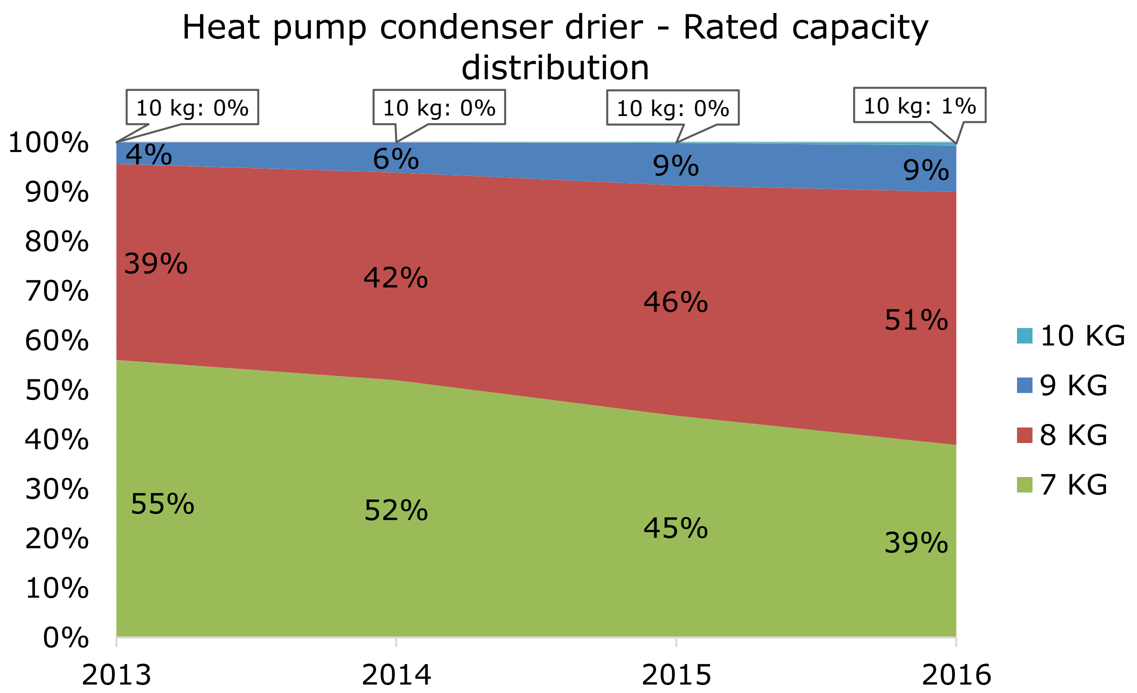

Figure 18: Market distribution of rated capacity for condenser heat pump tumble driers, 2013-2016

The heat pump tumble driers mostly have a rated capacity of 7 or 8 kg, with and increasing trend of 8 and 9 kg machines while 6 and 7 kg machines are decreasing in the market.

The same trend in rated capacity is seen for heat element driers, both condensing and air-vented (see Figure 19 and Figure 20).

The heat element condenser driers are, to a large extent, similar to heat pump driers, except that the 7 kg machines are predominant. For heat element air-vented driers, the 6 kg machines also have a large market share, but is declining in favour of 7 kg machines.

The gas drier market is the only one for which the rated capacity shows a declining trend, and even though the 7 kg machines are dominant, the share of <5 kg machines is increasing, while gas driers with all other rated capacities are not present on the market.

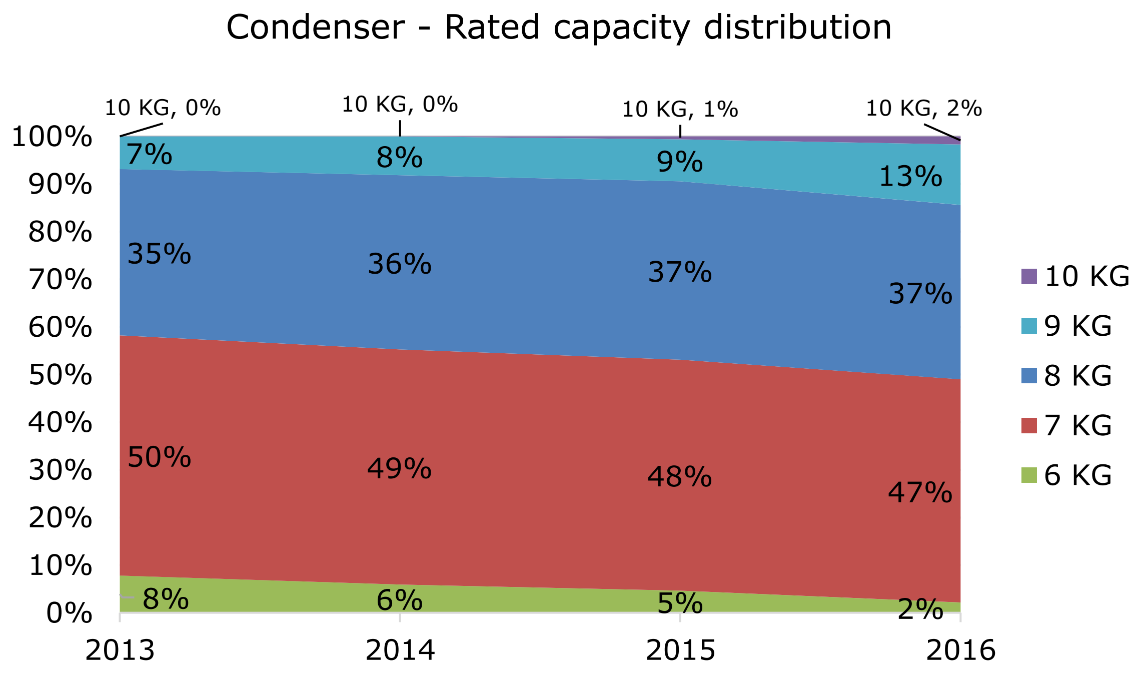

Figure 19: Market distribution of rated capacity for condenser tumble driers, 2013-2016

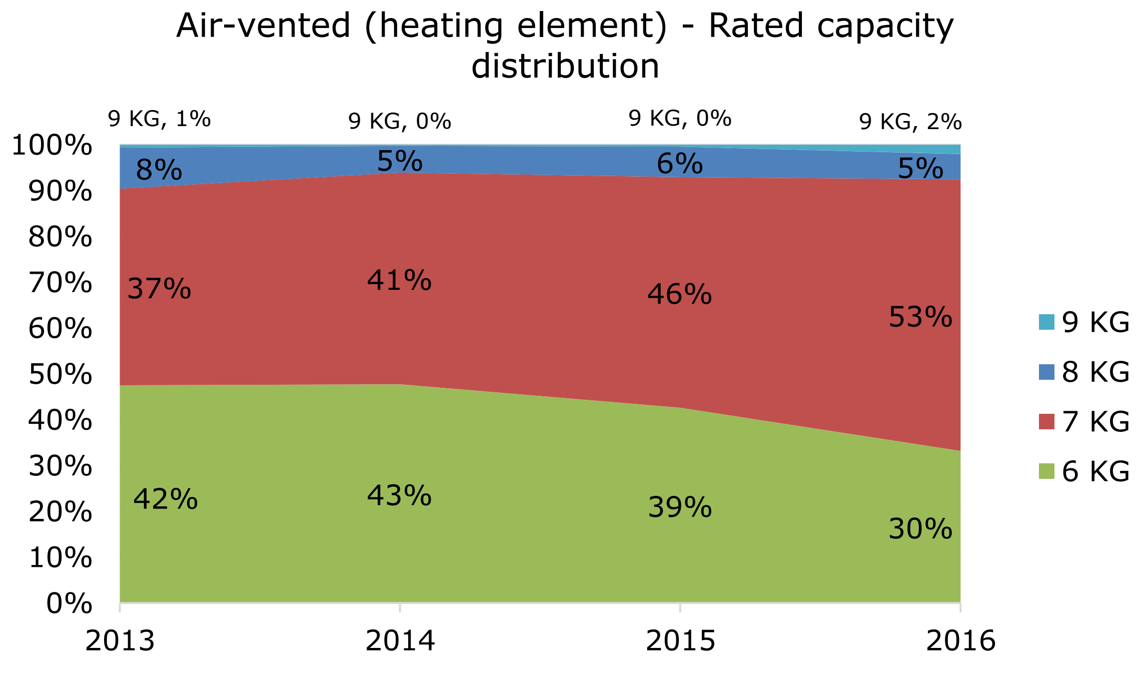

Figure 20: Market distribution of rated capacity for air-vented tumble driers, 2013-2016

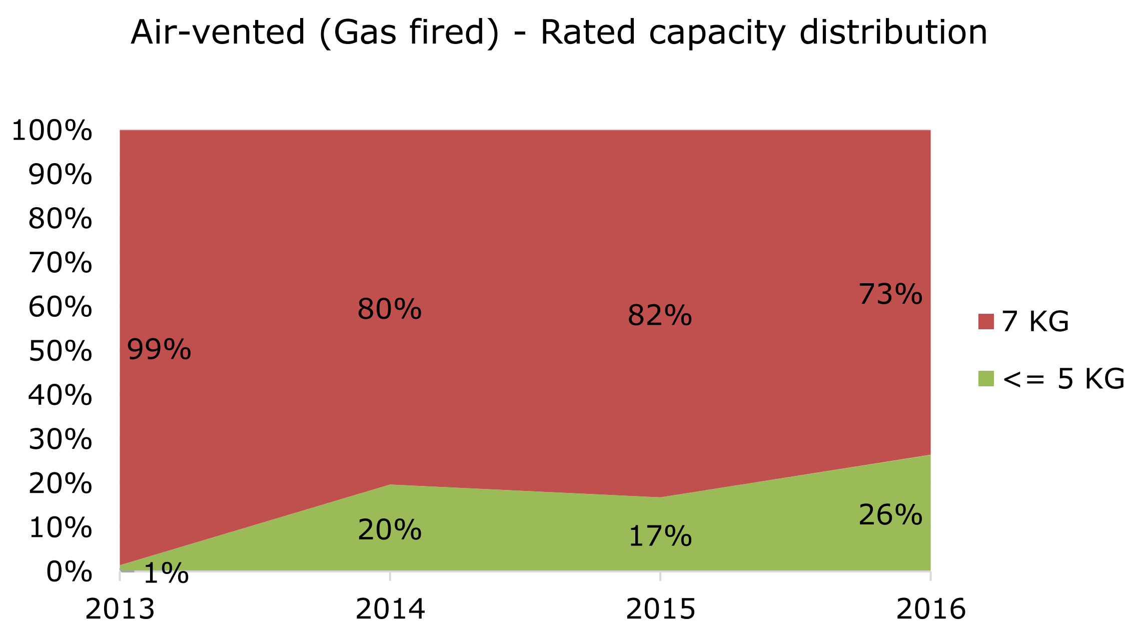

Figure 21: Market distribution of rated capacity for gas tumble driers, 2013-2016

Summarizing the figures above with sales-weighted averages, a general trend can be seen in Figure 22. All driers but the gas driers are steadily increasing in rated capacity.

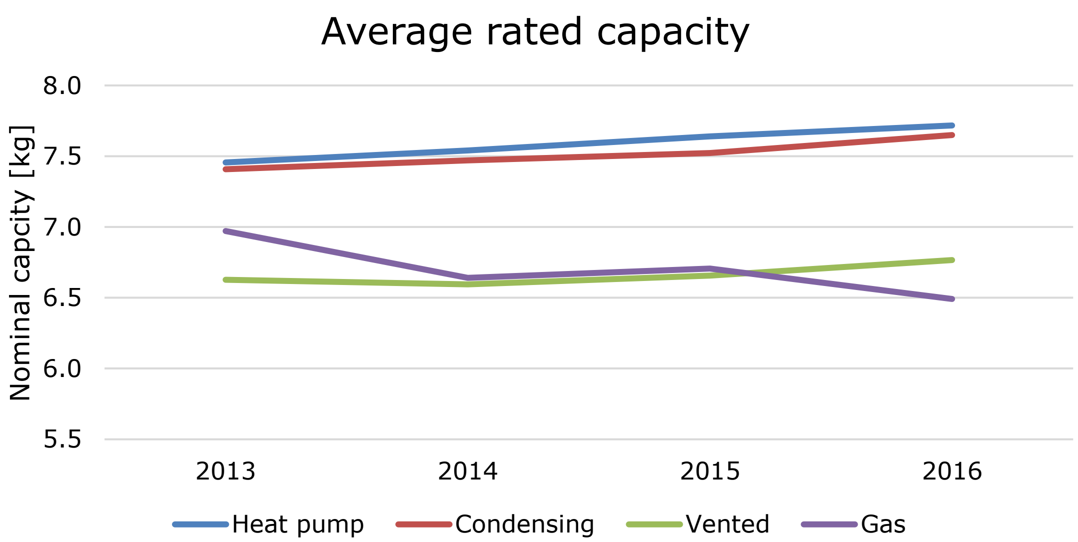

Figure 22: Sales-averaged rated capacity for all drier types.

Cycle time

The cycle time declared on the energy label is the duration of the standard cotton programme at full load, excluding any delay (timer) set by the end user. There is no specific ecodesign requirement for the cycle time.

The market distribution for all technologies is largely unchanged, except for those where the "not declared" share is decreasing, which causes other categories to increase.

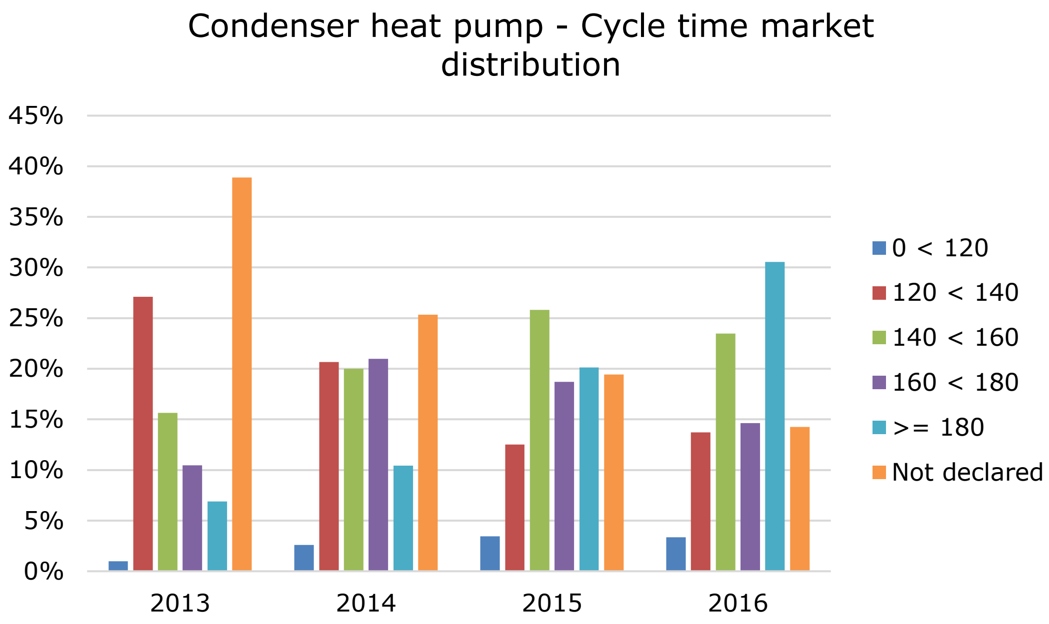

Figure 23: Cycle times in minutes of heat pump driers, 2013-2016

For heat pump driers (Figure 23), the majority of the market in 2016 had cycle times above 180 minutes, while in 2013 the majority (of declared machines) had cycle times between 120 and 140 minutes. However, since the 140-160 minutes market share has increased and the 160-180 has simultaneously decreased, there is no overall trend to the cycle time.

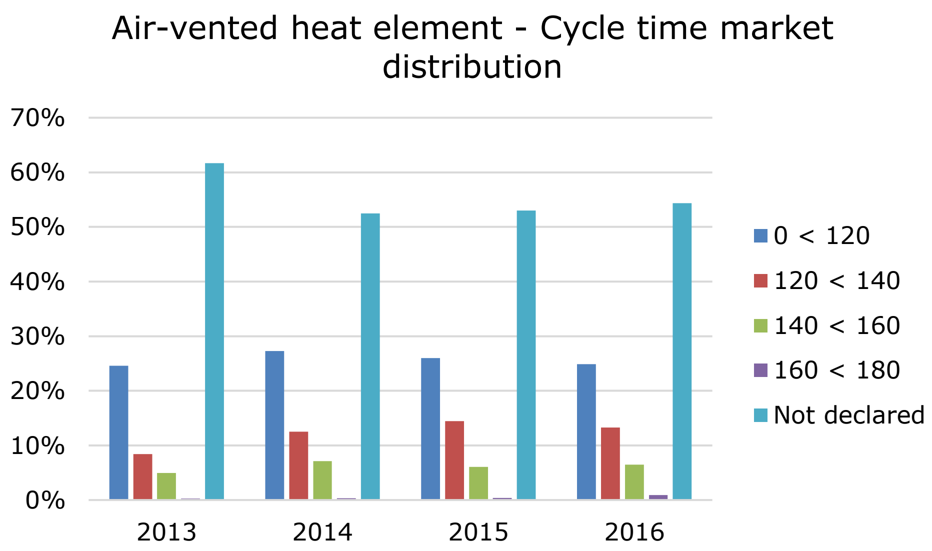

Figure 24: Cycle times of air-vented driers, 2013-2016

For the air-vented driers (Figure 24) there is almost no change in the market from 2013 to 2016, and the "not declared" share continues to be more than 50%.

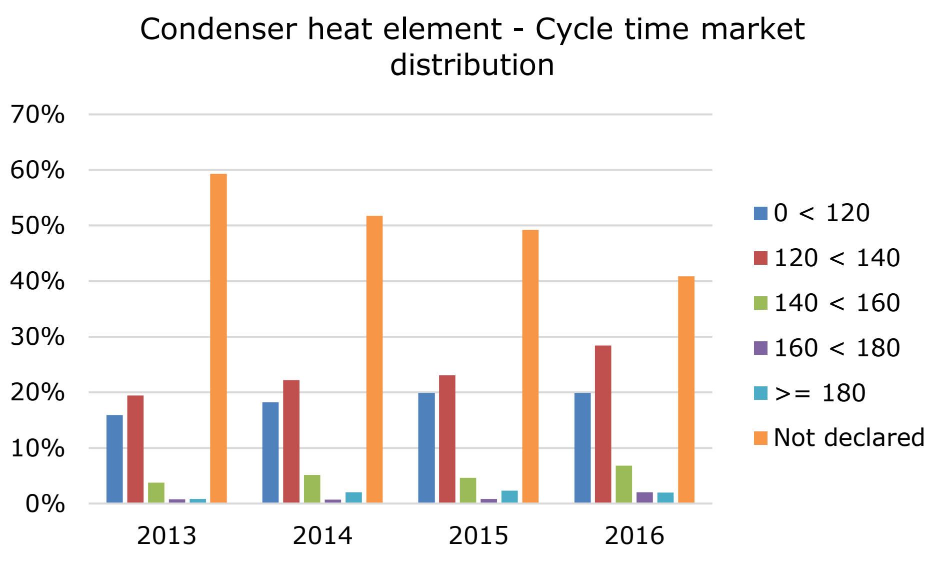

Figure 25: Cycle times of heat element condenser driers, 2013-2016

For the condenser driers (Figure 25), the not-declared share is very high, but declining from 2013 to 2016. It seems that the share of machines in all of the cycle time intervals increase, as “not declared” decreases, hence it is not possible to see a market development from the data.

This is not the case for gas-fired air-vented driers, where the majority of the driers covered by GfK data do not declare cycle time thus no trend is possible to identify (Figure 28).

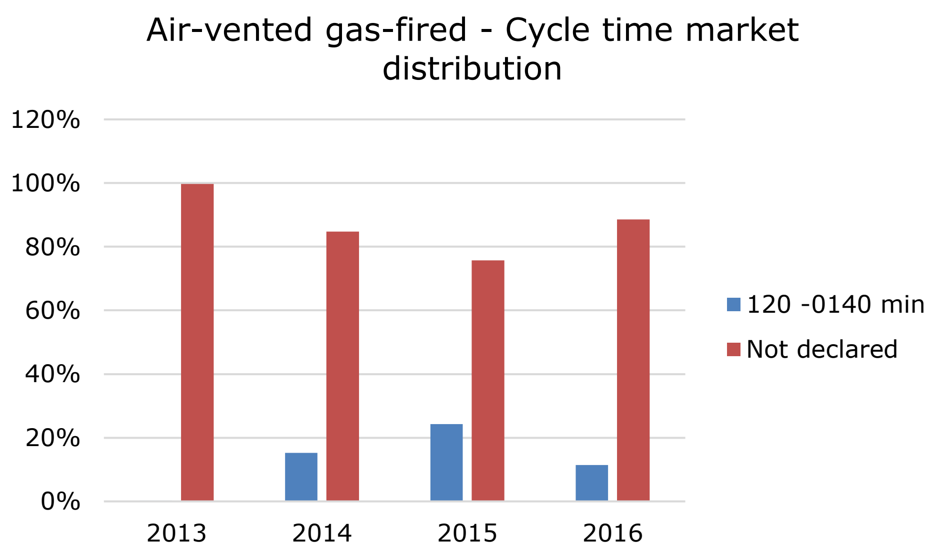

Figure 26: Cycle times of gas driers, 2013-2016

Noise

The Ecodesign Regulation does not set any specific requirements for the sound power level, but it is required to be shown on the label as a value in dB. The sound power level is based on the standard cotton programme at full load. There seems to be no general trend in sound power level for any of the drier technologies.

For heat pump tumble driers (Figure 27), the largest market share has a noise level of 65 dB, even though it is decreasing, while the market share of driers with noise level 66 dB is increasing. The least noisy heat pump driers (<63 and 64 dB) increased from 2013 to 2016, but the market share is still low and the trend is not unambiguous.

The air-vented driers (Figure 28) mostly have a sound power level >66 dB, or it is nor declared. The market share of machines with noise level 66 dB or below, is roughly unchanged from 2013 to 2016.

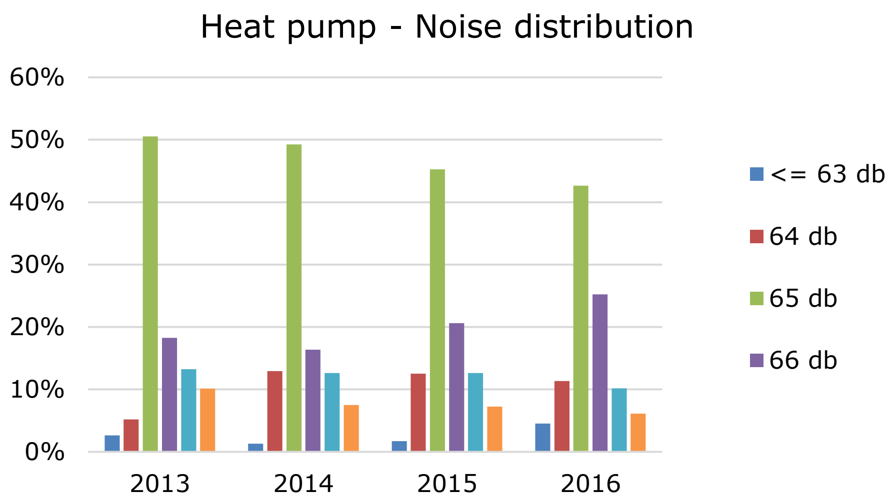

Figure 27: Heat pump driers noise distribution, 2013-2016

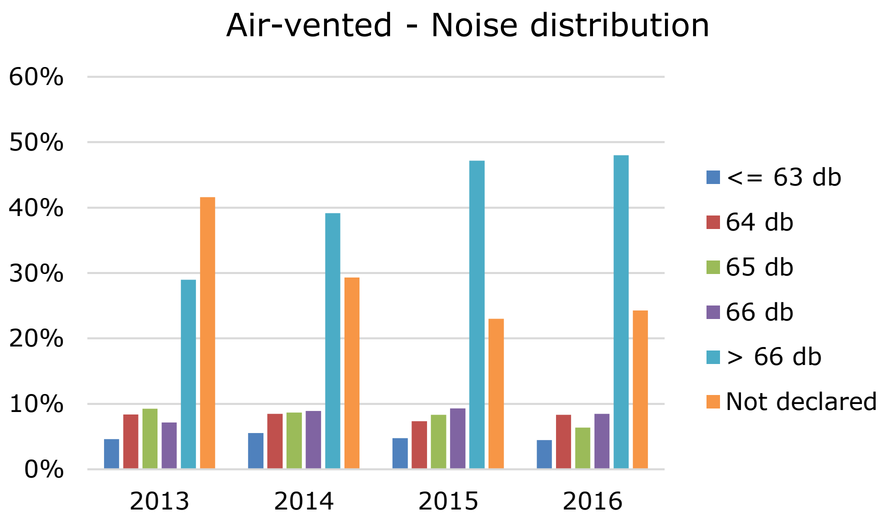

Figure 28: Air-vented driers noise distribution, 2013-2016

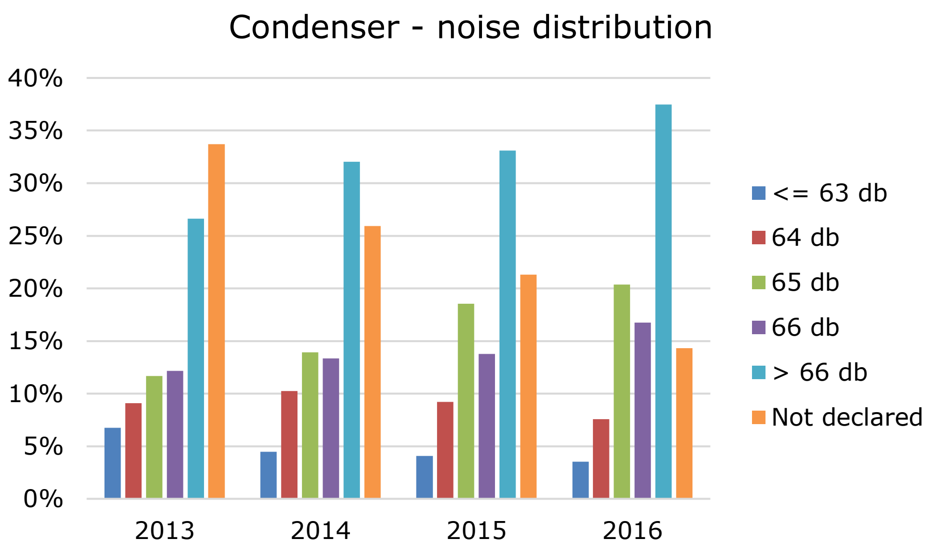

Figure 29: Condenser driers noise distribution, 2013-2016

For the condenser driers (Figure 29) the majority of the market is also driers with >66 dB sound power level, and it has continuously increased, while the not declared share decreased from 2013 to 2016. The share of driers with sound power levels 65 and 66 dB also increased, while the <63 and 64 dB driers decreased.

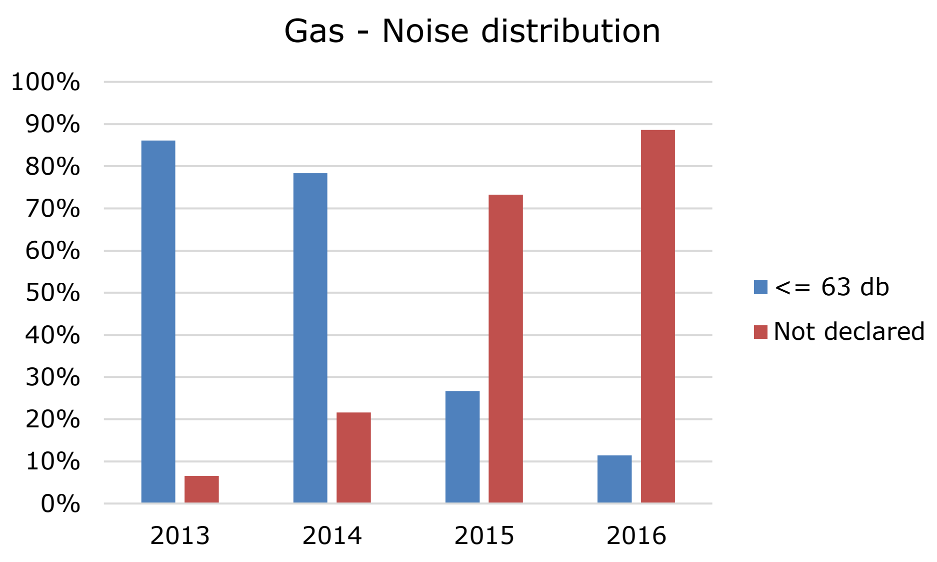

Figure 30: Gas driers noise distribution, 2013-2016

The data for the gas driers (Figure 30) is very limited due to the very low market share of this technology and the only sound power levels with data points is the <63 dB category. The rest was labelled as "not declared" in the data provided by GfK, which increased significantly from 7% to 89% from 2013 to 2016. The share of gas driers for which the sound power level is known is thus only 11% for 2016.

2.3.3 Future impact of ecodesign requirements on air-vented driers

Looking at the predicted sales figures and stock values for air-vented driers in Table 9 and Table 14 respectively, it is clear that existing market forces are regulating the market towards using condenser driers instead of air-vented. This might nullify the effects of new ecodesign Regulations on these types of driers, as they are gradually being removed from the market on a voluntary basis.

Using the GfK data and stock calculations done in sections 2.2.2, and assuming a 10%[75] reduction of annual energy consumption (AEc) can be achieved in all air-vented driers sold after 2020, the total energy consumption reduction of air-vented driers can be seen in Figure 31.

[75] 10% was used as an indicative figure

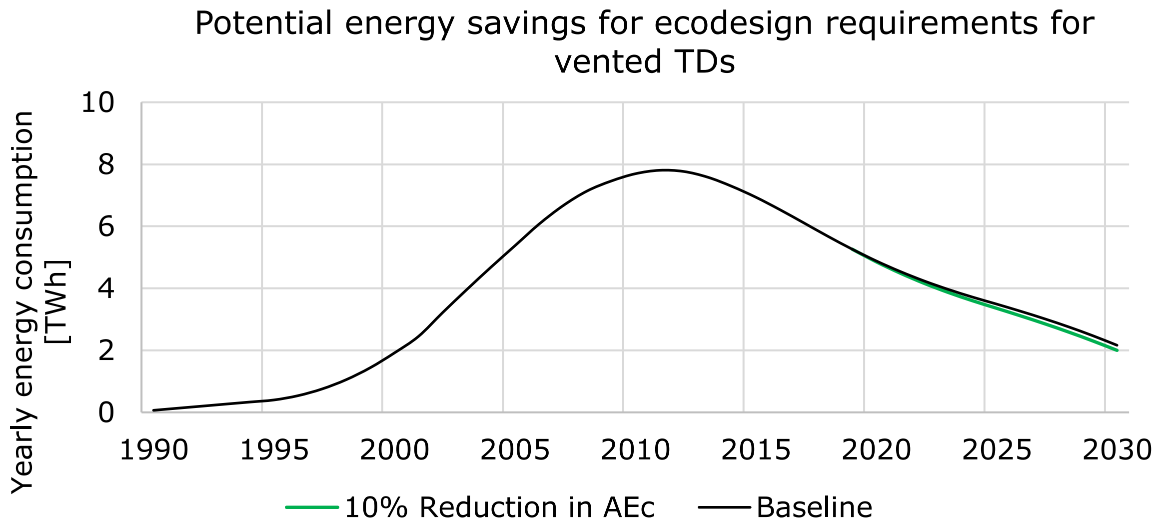

Figure 31: Effects on total energy consumption of air-vented driers, with a 10% reduction of new units sold after 2020. All baseline AEc assumed constant at 460 kWh/year.

The combined effects results in cumulative energy savings of 1.3 TWh of electricity between years 2020 and 2030. In percentage, this corresponds to 3.4% of the total energy consumption for air-vented driers in the same time period.

2.3.4 Market channels and production structure

The market for household tumble driers is characterised by a large number of manufacturers. Major players include, but is not limited to, BSH, Miele, LG Electronics, Samsung, Whirlpool, AEG, Electrolux, Candy, Gorenje, Vestel, and Whiteknight. Most manufactures produce both heating element (air-vented and condensing) and heat pump driers, but only the last manufacture produce gas fired driers. The market is thus dominated by large players, with very few SME's currently on the market.

2.4 Consumer expenditure base data

The average consumer prices and costs experienced by the end-user throughout the product lifetime are determined by unit prices in the following categories:

- Purchase price
- Installation costs
- Repair and maintenance costs
- Electricity and gas prices
- End of life cost

Each of the other costs are explained in the following sub-sections. The costs are shown as unit prices for each product, maintenance event, kWh electricity and so on. The total life cycle costs, which also depend on use patterns and frequency of events, is discussed in task 5.

2.4.1 Interest and inflation rates (MEErP method for LCC calculation)

All economic calculations will be made with 2016 as base year, as this is the latest whole year for which data is available. Inflation rates from Eurostat[76] will be used to scale purchase price, electricity prices etc. to 2016-prices. Furthermore, a discount rate of 4% will be used in accordance with the MEErP methodology.

2.4.2 Consumer purchase price

The consumer purchase price including VAT was calculated from the data on unit sales and total market value collected by GfK. The data was available for the years 2013-2016, and the average unit price for each tumble drier type is shown in Table 15.

Table 15: Unit retail prices in EUR for household tumble driers

Unit prices, EUR		2013	2014	2015	2016
Condenser	Heat pump	734	681	648	615
	Heating element	255	254	389	370
Air-vented	Heating element	245	338	266	248
	Gas-fired	245	338	465	374

As seen from the table, the price of heat pump tumble driers has decreased steadily from 2013 to 2016, as the technology matured and took over a larger share of the market. This price decrease happened despite the increase of heat pump driers in category A++ and A+++ (24% and 1% in 2013 compared to 62% and 14% in 2016).

The air-vented heat element technology driers stayed more or less on the same price level despite some fluctuations, and the energy efficiency class distribution also stayed more or less constant over the four reported years with the majority in energy class C (75-78%).

The heat element with condensing technology driers increased in price over the four years, which is consistent with approximately 20% of the market shifting from energy class C to B for in the same period (Class B share increasing from 71% in 2013 to 93% in 2016).

Based on the actual price data shown in Table 15, the purchase prices in the entire period from 2000 to 2030 were extrapolated, using the calculated growth rates.

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[76] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:HICP_all-items,_annual_average_inflation_rates,_2006-2016_(%25)_YB17.png

2.4.3 Installation costs

The installation of electric tumble driers can be done by the end-user or by a professional, while gas appliances need to be installed by a professional. Furthermore, use of gas is only possible where a gas connection is available.

The preparatory study does not include the installation costs[77], and while the impact assessment claims to do so[78], their cost analysis is based on data form the preparatory study, in which the installation is not included. According to both the preparatory study and the impact assessment, the installation cost is large enough to have an effect on the market share of gas tumble driers[79]. In the Impact Assessment it is noted that under "certain conditions and with certain models, the LLCC level is achievable for gas driers", but that this is without taking into account the installation costs, "which can be a substantial addition to the overall costs"[80]. Hence, both studies conclude that the installation cost of gas driers cannot be neglected, but the low market share makes it very difficult to find the actual cost.

Most gas driers are sold in the US, and so US installation costs are easier to find, as seen in Table 16, where most prices had to be converted form US dollars to euros. The table shows the highest and lowest price found by six different sources. If only one price is stated, it is the average reported. It was not possible to determine why there was such a large difference in installation costs, but it could have something to do with whether or not it is the company selling the machine that also offers installation, or if the installation is done by someone else. The only EU source was Which.co.uk[81], where it was stated that the cheapest quotes we between 113 and 170 Euro (£100-£150). The overall installation price, according to the sources shown in Table 16 is this around 130 Euro.

[77] Prep. Side 306: "Costs do not include installation at the site"

[78] IA side 26-27: The options are assessed using scenarios in which the consumer costs (purchase price, installation and maintenance - electricity is treated separately) are calculated taking into account the development of average efficiency. The data for these costs stems from the preparatory study under task 6.

[79] Prep study side 163 og IA side 12

[80] IA side 20

[81] http://www.which.co.uk/reviews/tumble-driers/article/gas-and-heat-pump-tumble-driers

Table 16: Installation costs for gas driers

USD		EUR[82]	
Low	High	Low	High
96	191[83]	81	162
79	177[84]	67	150
282[85]		239	
81	155[86]	67	131
		113	170[87]
111[88]		94	

For electric appliances the installation is often significantly cheaper, even if it is installed by a professional, which does not necessarily happen.

2.4.4 Electricity and gas prices

The annual electricity and gas prices from the PRIME Project[89] will be used for the economic calculations in this study. The electricity prices were reported as €/toe (ton of oil equivalent) in fixed 2013-prices. They were therefore converted to €/kWh and corrected for inflation to fixed 2016-prices as shown in Table 17.

Table 17: Electricity and gas prices with 2016 as base year will be used

	Price in €/kWh (2016-prices) for households	
2005	0.159	0.047
2010	0.175	0.062
2015	0.194	0.072
2020	0.207	0.077
2025	0.213	0.081
2030	0.216	0.085

The prices were given every fifths year and linear interpolation will be used in between.

2.4.5 Repair and maintenance costs

The cost of repair consists of the labour cost and the cost of the spare parts. An example of repairing a tumble drier with a broken heating element is:

[82] 1 USD = 0.847364273 Euros
[83] https://www.homewyse.com/services/cost_to_install_gas_drier.html
[84] https://porch.com/project-cost/cost-to-replace-a-gas-drier
[85] https://www.homeownershub.com/maintenance/cost-to-install-a-new-gas-drier-old-one-broke-155357-.htm
[86] https://www.proreferral.com/hg/how-much-does-drier-installation-cost/
[87] http://www.which.co.uk/reviews/tumble-driers/article/gas-and-heat-pump-tumble-driers
[88] https://www.proreferral.com/hg/how-much-does-drier-installation-cost/
[89] https://ec.europa.eu/eurostat/cros/content/prime_en

- Prices for heating elements for electric driers vary with type of element and model, but they typically range from $35 to $100. Gas ignition coils are similarly priced, and the price shouldn't be above $100 for one.
- Labour cost (if needed) which varies greatly across Europe. See Figure 33.

In cases where driers need to be repaired by a professional, the average EU average labour cost in the category “Industry, construction and services (except public administration, defence, compulsory social security)” is used, as shown in Table 18. The labour cost levels are based on the latest Labour Cost Survey (currently 2012) and an extrapolation based on the quarterly Labour Cost Index (LCI). The data covered in the LCI collection relate to total average hourly labour costs[90].

Table 18: Average total labour costs for repair services in euro per hour

	2000	2004	2008	2012	2013	2014	2015	2016
EU-28 countries, EUR/h	16.7	19.8	21.5	23.9	24.2	24.5	25.0	25.4

Though the labour costs vary greatly across Europe and are presented in **Figure 32.** The labour cost in each country can affect the consumers’ willingness to repair.

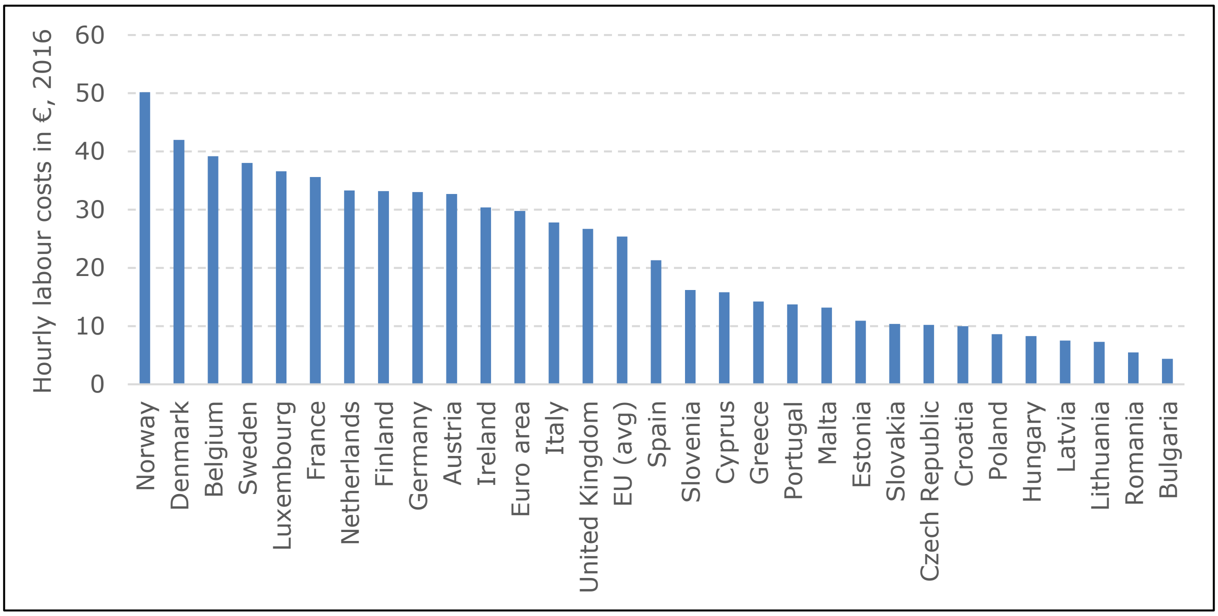

Figure 32: Hourly labour cost in €, 2016 for European countries

2.4.6 End-of-life costs

The disposal costs are paid by the end-user buying the product in the form of the Eco tax under the WEEE Directive. For a tumble drier, this corresponds nowadays to a fee of 80 to 120 EUR/tonne. This fee is adjusted on a country basis and by product category depending

[90] http://ec.europa.eu/eurostat/cache/metadata/en/lc_lci_lev_esms.htm#unit_measure1475137997963

on recycling costs. The fee is not always included in the final product price, and even if it is, it is not always allowed to be visible at the point of sale.

3. Review of user behaviour

3.1 Consumer behaviour related to use

3.1.1 Parameters influencing the energy consumption of the drier

The performance of the driers is based on two parameters:

- the annual energy consumption (AEc)
- the condensation efficiency (C)

The calculation method of the two parameters are defined in Commission Regulation (EU) No 932/2012 and Commission delegated Regulation (EU) No 392/2012 and reflects the consumer behaviour related to the use of tumble drier. They are presented here because of their utmost importance to the review of the driers' user behaviour.

Annual Energy Consumption (AEC)

The Annual Energy consumption is based on measurements of energy consumption and the cycle time. The measurements are conducted with the standard cotton program reducing the moisture content of the test fabric from 60% to 0%. The measurements are made with both full load and partial load and the Regulation includes an inherent assumption that for every 7 drying cycles, the machine is full loaded 3 times and part loaded 4 times. Thus, the weighted energy consumption and time consumption are calculated as:

$$E_t = \left(3 * E_{dry} + 4 * E_{dry½}\right)/7$$

$$T_t = \left(3 * T_{dry} + 4 * T_{dry½}\right)/7$$

The identifiers "dry" and "dry½" indicate the values measured at full and half load respectively. The weighted energy, E_t, and time, T_t, are then used to calculate the annual energy consumption, AE_C:

$$AE_C = E_t * 160 + \frac{P_o * \frac{525\,600 - (T_t * 160)}{2} + P_l * \frac{525\,600 - (T_t * 160)}{2}}{60 * 1000}$$

The first part of the equation is simply the weighted energy consumption per cycle multiplied with 160 cycles per year. The last part of the equation is the energy consumption in off and left-on mode. With the equation it is assumed that the drier is in off mode half of the time it is not in use, and in left-on mode the other half. Thus, the power consumption (in watts) in off mode, P_o, and left-on mode, P_l, are each multiplied with the number of minutes in one year (525 600) minus the time the machine is in use (i.e. 160 times T_t minutes) and divided by two. Hence the numerator of the fraction constituting the second part of the equation equals the total power consumption in off and left-on mode of the drier in one year, in the unit Watt-minutes. The denominator of the fraction is simply unit conversion to kWh. The AE_C is thus the energy consumption in both active and non-active modes in a whole year.

For tumble driers with power management an alternative formula exists, where the drier automatically goes to off-mode (from left-on) a specific time, T_l, after a program is finished. For these driers the AEc is calculated instead as:

$$AE_C = E_t * 160 + \frac{\{(P_l * T_l * 160) + P_o * [525600 - (T_t * 160) - (T_l * 160)]\}}{60 * 1000}$$

In this equation the time in left-on mode is known, and therefore the energy consumption in left-on is simply the left-on power, P_l, multiplied with the left-on time, T_l, and 160 cycles per year. The drier is then assumed to be in off-mode the remainder of the year, and the off power, P_o, is therefore multiplied with the total minutes in one year (525 600) minus the time in use and in left-on.

For gas-fired tumble driers, the energy consumption is primary energy in the form of gas, compared to electricity which is a secondary type of energy. Therefore, the E_{dry} and $E_{dry½}$ have to be scaled with the primary energy factor f_g=2.5:

$$E_{dry} = \frac{Eg_{dry}}{f_g} + Eg_{dry,a}$$

The energy efficiency scale is based on the EEI value, which is derived from the AE_C and the SAE_C (Standard Annual Energy Consumption) values of the drier, and calculated as a percentage:

$$EEI = \frac{AE_C}{SAE_C} * 100$$

The SAEc is based on the rated capacity, c, of the drier in kg and calculated as:

$$SAE_C = 140 * c^{0.8}$$

Where the 140 and 0.8 are arbitrary scaling factors.

For air-vented appliances the SAEC is calculated as:

$$SAE_C = 140 * c^{0,8} - \left(30 * \frac{T_t}{60}\right)$$

Which lowers the SAEc and thus increases the EEI (by lowering the denominator in the EEI formula) in order to account for secondary energy consumptions.

The specific ecodesign requirements are based on the calculated EEI values and introduced in two tiers (see Table 19).

Table 19: Ecodesign requirements for tumble driers

	Tier 1, November 2013	Tier 2, November 2015
EEI vented driers	<85	<85
EEI condenser driers	<85	<76

The EEI level also forms the basis for the energy efficiency scale, as seen in Table 20.

Table 20: Distribution of energy efficiency classes based on EEI values

Energy efficiency class	Energy Efficiency Index, EEI
A+++	EEI < 24
A++	24 ≤ EEI < 32
A+	32 ≤ EEI < 42
A	42 ≤ EEI < 65
B	65 ≤ EEI < 76
C	76 ≤ EEI < 85
D	85 ≤ EEI

In summary, the energy efficiency of tumble driers in ecodesign and energy labelling Regulations is defined by the following parameters:

- Energy consumption pr. cycle at full and half load
- Time duration pr. cycle at full and half load
- Energy consumption in off-mode
- Energy consumption in left-on mode
- Time the drier takes to switch automatically to off-mode after being in left-on mode, once a drying program is finished (when drier counts with a power management function)
- The standard energy consumption of the drier used as reference value, which is calculated from the drier's rating capacity; this includes a penalization factor for air-vented driers

Furthermore, additional assumptions play an important role on the calculation of the energy efficiency:

- For every 7 drying cycles, the machine is full loaded 3 times and half loaded 4 times

- The driers are used 160 cycles per year (i.e. ~3.1 cycles/week)
- When the drier is not in use, it is in off mode half of the time and in left-on mode the other half (when not having a power management function)

Condensation efficiency

The condensation efficiency is only relevant for condensing driers (incl. heat pump driers), and not for air-vented appliances (including gas driers). The average condensation efficiency is calculated based on measurements as a percentage:

$$C = \frac{1}{(n-1)} \sum_{j=2}^{n} \left(\frac{W_{wj}}{W_i - W_f} * 100 \right)$$

The percentage of collected water, W_{wj}, compared to the water removed from the clothes is calculated. Water removal is based on the sample weight before and after the drying process (Wi, and W_f respectively). The measurements after each test run shall be done at least four times (n=4), and summarised for test run j=2, up to n. The average is then calculated by multiplying the sum with the number of test runs summarised (which is n-1).

The weighted condensation efficiency is then calculated in a similar way to weighted energy consumption and cycle time:

$$C_t = \left(3 * C_{dry} + 4 * C_{dry½}\right)/7$$

The specific ecodesign requirements related to condensation is shown in Table 21.

Table 21: Ecodesign requirements for condensation efficiency of condenser driers

	Tier 1, November 2013	Tier 2, November 2015
Condensation efficiency	≥60%	≥70%

In summary, the condensation efficiency of tumble driers in ecodesign and energy labelling Regulations is defined by the following parameters:

- Percentage of water collected pr. cycle at full and half loads
- Sample weight of water in clothes before and after the drying process
- Number of test runs

Furthermore, the assumption concerning the distribution between full and half load play also an important role on the calculation of the energy efficiency:

For every 7 drying cycles, the machine is full loaded 3 times and half loaded 4 times

3.1.2 User Behaviour

Data sources and main parameters

Summarising, the main parameters affected by user behaviour that are important to the energy and condensation efficiency of a tumble drier are:

- The average number of cycles per week
- The loading of the drier per cycle, i.e. how much is the machine filled in average with respect to its rated capacity
- The time the machine is left on left-on mode by the user before it is switched off
- Additionally, the cleaning frequency of lint filter and heat exchanger is important to ensure consistent performance of the machine, as failing to regularly do so will increase the energy consumption per cycle[91] [92]

Two online surveys are available that cover a wide range of aspects concerning the user behaviour of tumble driers in the EU market by consumers: the 2009 preparatory study and the study conducted for APPLiA by InSite Consulting[93]. Other studies on washing behaviour are also available. Due to the interlink between washing and drying loads, these studies can be used to assess the general laundry behaviour and/or to validate the drying behaviour studies.

Results from the drying studies are summarised in Table 22. Results from the washing studies are summarised in Table 23.

Note that the APPLiA study only covered people who owned a tumble drier. Similarly, the preparatory study consumer survey covered a sample of people with 86% owning a tumble drier. This is consequently far from the penetration rate of 23% found in task 2. Values in Table 22 and Table 23 represent mostly people owning a tumble drier and not the whole of EU28. This can also explain the large difference in drying amounts between the APPLiA and the Alborzi study.

There are generally two different ways the studies are conducted, by online surveys or by measuring the actual load used in each cycle ("Metering studies"). The online surveys from the preparatory study, APPLiA, and Alborzi have by far the largest statistical population and geographical scope, but also introduce subjectivity as these are not 'metering studies' and thus answers are being subject to personal bias and subjectivity.

[91] According to input from stakeholders
[92] "EXPENSIVE MEASURES FOR THE ENVIRONMENT", Berge et al., RÅD & RÖN No. 7, 2012
[93] APPLiA and InSites Consulting. (2018). Tumble dryer usage and attitudes: A survey in 12 European countries (not publicly available). Draft version.

Table 22: Key findings for drying behaviour studies.

Data source	***Preparatory study*[94]**	**APPLiA consumer questionnaire[93]**
Author	*PWC*	InSites Consulting
Data source, age	Online survey, 648 valid surveys, 2008.	Online survey, 2426 valid surveys, 2018.
Countries	UK, FR, PL	NL, UK, FR, GE, ES, IT, PL, CZ, HU, FI, SE, TR
Scope	Drying behaviour	Drying and washing behaviour
Average load/cycle	4.5kg / 3.4kg[95]	5.3[96]kg
Average nominal capacity	5.7 kg	7.1 kg
Frequency of use [Cycles/Person/Week]	0.7 (Summer) 1.1 (Winter)	0.6 (Summer) 0.8 (Winter)
Frequency of use [Cycles/Household/Week]	2.3 (Summer) 3.6 (Winter)	1.7 (Summer) 2.4 (Winter)
% of washing load that is dried in tumble drier during winter	50%	72%
% of washing load that is dried in tumble drier during summer	24%	51%

[94] Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16, Ecodesign of Laundry Dryers, PriceWaterhouseCoopers, 2009.
[95] The conducted online survey resulted in 4.5kg. 3.4kg was chosen after stakeholder consultation, to keep consistency with washing machine studies.
[96] Based on average loading %, and average machine capacity.

Table 23. Available studies on washing behaviours.

Data source	Study 1 [97]	Study 2[98]	Study 3[99]	Study 4[100]
Author	Berkholz et al.	Krushwitz et al.	Alborzi et al.	P&G
Data source, age	30-day metering study, 100 households, 2007	28-day metering study, 236 households, 2009.	Online survey, 4843 valid surveys, 2015.	Metering study, 276 households, 2015
Countries	DE	DE	CZ, DE, FI, FR, HU, IT, PL, RO, SE, ES, UK	FR
Scope	Washing machines	Washing behaviour	Washing machines, drying behaviour	Washing machines
Average washing load/cycle	3.4kg	3.3kg	5.7kg[101]	3.24kg
Average capacity (Washing machine)	5kg	5kg	6.5kg	6.24kg
Frequency of use [Cycles/Person/Week]	1.7	1.7	1.5	-
% washing load that is dried in tumble drier during winter	-	-	19%	-
% washing load that is dried in tumble drier during summer	-	-	11%	-

Cycles per week

The number of cycles per week is affected by the washing cycles per week, as all the dried laundry is wetted through the washer.

The amount of **cycles per week** has decreased from the preparatory study (2008) to the APPLiA survey (2018). This is consistent with the increase in rated capacity but might also be due to the very different scopes of the surveys.

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[97] Berkholz P., et al: Verbraucherverhalten und verhaltensabhängige Einsparpotenziale beim Betrieb von Waschmaschine, Shaker-Verlag, 2007

[98] Kruschwitz, A.; Karle, A.; Schmitz, A. & Stamminger, R. (2014). Consumer laundry practices in Germany. International Journal of Consumer Studies, 38(3), pp. 265–277.

[99] A Alborzi, F.; Schmitz, A. & Stamminger, R. (2017). Washing behaviour of European consumers 2017, *Shaker Verlag*

[100] Proctor & Gamle: Load Weight Study - France 2015, Workshop on how to improve testing methods for washing machines and washer-dryers, Annex 6, 2016.

[101] Calculated as a weighted average, based on consumer loading behaviour on physical loading capacity, fig. 87.

The APPLiA survey shows that especially the northern countries (I.e. Sweden, Finland) use their tumble driers significantly more during the winter. This might also express the large difference in the percentage of laundry being dried at summer/winter times between the two studies. As the preparatory survey did not include any of these, the comparison might not be justified. The APPLiA study is used as reference, at 1.7 & 2.4 cycles per week per household during the summer and winter respectively.

The Alborzi study also investigated the percentage of drying done in tumble driers. These figures significantly differ from the other studies. No explanation on why is however available. The amount of **cycles per week** has decreased from the preparatory study (2008) to the APPLiA survey (2018). This is consistent with the increase in nominal capacity but might also be due to the very different scopes of the surveys.

Loading of the drier

As the market trend is favouring driers with larger capacities (see Figure 22) two things can happen to consumer loading behaviour:

a. The loading behaviour can remain constant, meaning that the amount of laundry loaded per cycle is unchanged compared to 2008[102], or
b. the loaded laundry can increase, which could mean fewer but larger cycles.

The loading of the drier is important as it affects the *specific* energy consumption of the drier in terms of the energy used per kg of dried laundry. According to input from industry, a fixed energy is required to heat up the drier itself, regardless of the amount of loaded laundry. This increases the specific energy consumption at partial loads[103]. Furthermore, as the drum volume is less full at lower loads, the drying air comes into less laundry-surface area, which reduces the effectiveness of the drying and hence increases the energy consumption.

Some manufactures use the same drum volume independently of the nominal capacity. The change in capacity is thus based on motor sizes and heating capabilities instead. Other manufactures differentiate between drum volumes between models at different rated capacities. For manufactures using the same drum volume for driers at capacities of i.e. 7kg and 9kg, the increase in specific energy consumption will be more significant, compared to manufactures differentiating between drum volumes.

The effect is visualised in Figure 33 where specific energy consumption at full and half load operations are shown for 177 drier models on the market. Differences up to 14% in energy

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[102] Year of survey used in the preparatory study.
[103] “Partial” here meaning a drier not loaded at 100% nominal capacity.

consumption are observed. Note that the increase in energy consumption at 9 kg might be due to insufficient data points, as few heating element driers are with 9kg+ capacities.

Table 24 lists each drier type and their increase in specific energy consumption. The difference in specific energy consumption between full- and half load operations decreases with a higher rated capacity. This might be because physical dimensions (and in some cases, the drum volume) of the driers do not increase, even though the nominal capacity does. The energy required to heat up the drier itself remains to some extend constant, which is hence marginalized at higher rated capacities.

For heat pump driers, a special case exists. For some top performing driers with heat pump technology (A^{+++}), a variable speed drive can be used with the compressor motor. This enables the heat pump circuit to reduce the compressor speed at partial loads, and thus decrease the pressure differences (and thus temperatures) in the cycle which results in a more thermodynamically efficient process. This increases the part load performance compared to other driers.

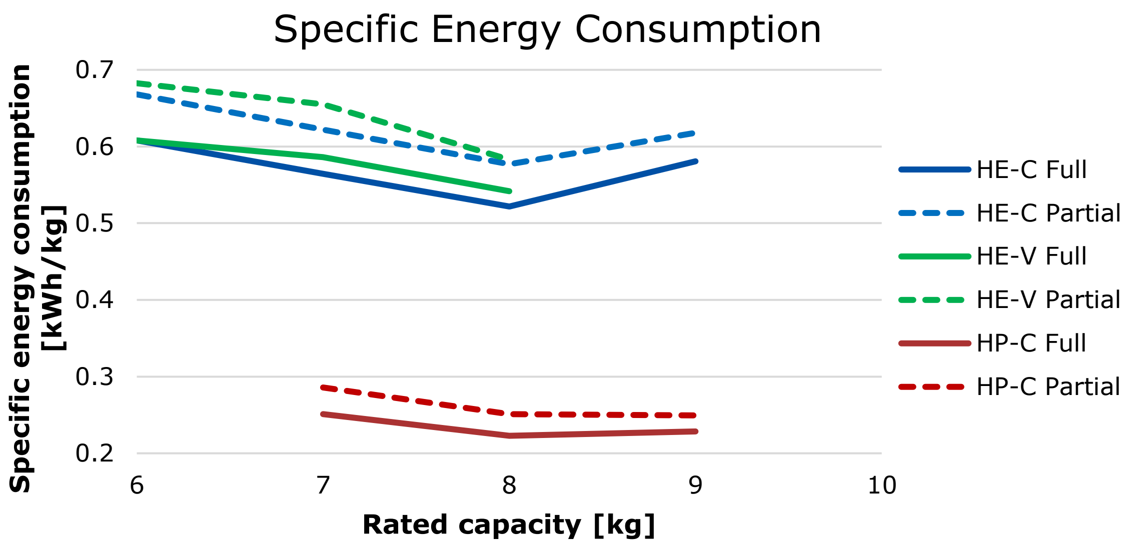

Figure 33: Specific energy consumption of three types of driers, at full and half (partial) load: Condensing with heating element (HE-C), Air-vented with heating element (HE-V) and condensing with heat pump (HP-C)[104]

[104] Source: APPLIA Model database 2016, n=177.

Table 24: Increase in specific energy consumption between full and half load operations[104]

Capacity [kg] / Type	HP-C	HE-C	HE-V
6	-	10%	12%
7	14%	10%	12%
8	13%	11%	8%
9	9%	6%	-
10	-	-	-

In terms of investigating the average load in the online surveys, different approaches where used. The preparatory study asked the consumers what their average load per cycle was, with ranges (e.g. 4-5kg) as options. Asking directly in terms of kilos of laundry the consumers processes per cycle can be especially difficult, as no reference point exists.

Alborzi addresses this by asking the consumers how they usually load their machine, in terms of the maximum physical capacity ("How do you usually load your machine?") of the machine (i.e. nominal load). This might also suffer from the same bias as the preparatory study, as consumers might have different ideas of what a "full" machine looks like.

The APPLiA study tries to remedy this be supplying pictures of a machine being loaded 25%-100%.

Three of the washing studies were made by measuring the processed laundry, hence removing the consumer bias uncertainties. The average washing load measured from these (3.4kg, 3.3kg, and 3.24kg) differs greatly from the Alborzi online survey study at 5.7kg. Even though the studies are only related to German and France households, Alborzi F. et al shows that at least from a consumer's point of view, German and French washing behaviour is close to the EU-28 average. [105]

Furthermore, comparing the tumble-drying loads from the preparatory- and APPLiA studies at 4.5kg and 5.3kg respectively, it is clear that the major difference between the different studies origins in the way they are fundamentally conducted. Even though the metering studies might prove to be more precise per data point, they are aimed at washing behaviour and with a significantly smaller statistical population and country coverage. The real drying average load is hence assumed to be somewhere between 3.2kg - 5.3kg, based on the P&G and APPLiA study respectively, as they consist of the newest available data.

[105] Alborzi, F.; Schmitz, A. & Stamminger, R. (2017). Washing behaviour of European consumers, fig. 87, 2017, *Shaker Verlag*

Cleaning frequency of filters

The APPLiA study investigated the cleaning frequency of the lint filter and condenser unit, shown in Figure 34. It shows that 45% of users clean the lint filter before every cycle as suggested by the manufactures, and that 29% of consumers with heat element condensing driers clean the condenser after every drying cycle. Failing to regularly clean the filters and condenser can lead to significant higher energy consumption and drying times[106].

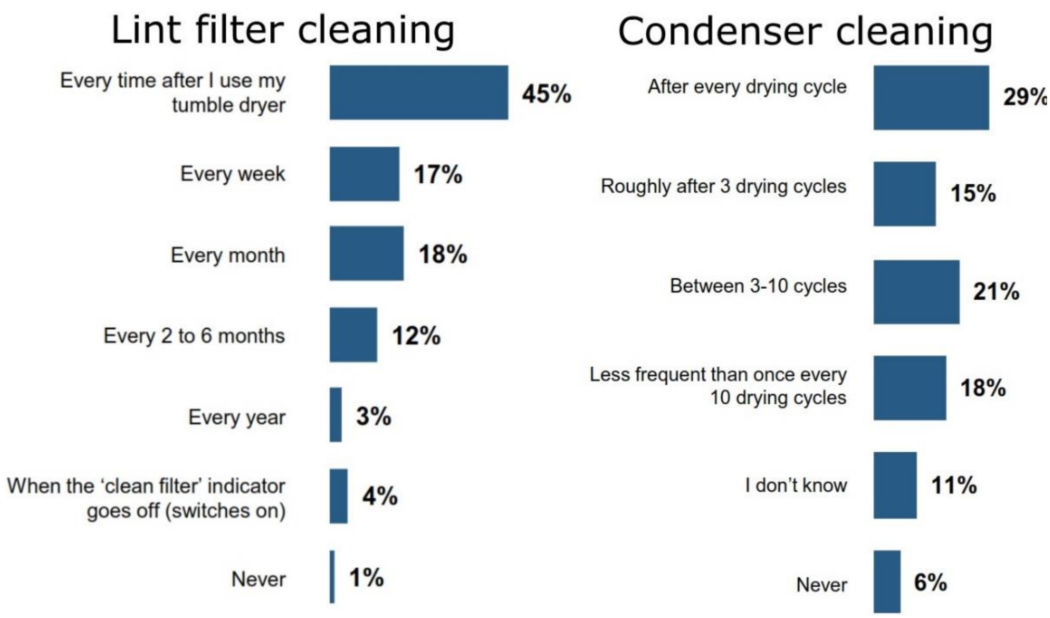

Figure 34: Cleaning behaviour of lint filter and condenser units.[102]

Conclusion

Comparing the average nominal (rated) capacity and the average load, the real energy consumption is heavily dependent on part load efficiencies of the driers. They are currently being tested for energy consumption at full and at half capacity (cf. Commission Regulation No 932/2012 Annex II), which gives an average loading testing factor of 71%[107] (see section 3.1.1 "Annual Energy Consumption" for reference).

If the average load at 3.2kg of laundry is used, then driers with a capacity of 7kg or more (Which is >98% of all sold condensing driers and >70% of air-vented driers in 2016, see Task 2) is on average running below even the partial loading capacity (i.e., half load) used in Regulation 392/2012. The driers are hence labelled at running conditions which they seldom, if ever, operate in. The introduction of driers with a capacity of 10kg seems especially disproportionate.

Using the P&G survey data, Figure 37 shows the washing machine loading behaviour of consumers, in respect to the nominal capacity of their washing machine. Assuming that all

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106 "EXPENSIVE MEASURES FOR THE ENVIRONMENT", Berge et al., RÅD & RÖN No. 7, 2012
107 (3*1+4*0,5)/7*100%

the dried laundry comes from washing machines, this can be linked to the tumble drier loading factor.

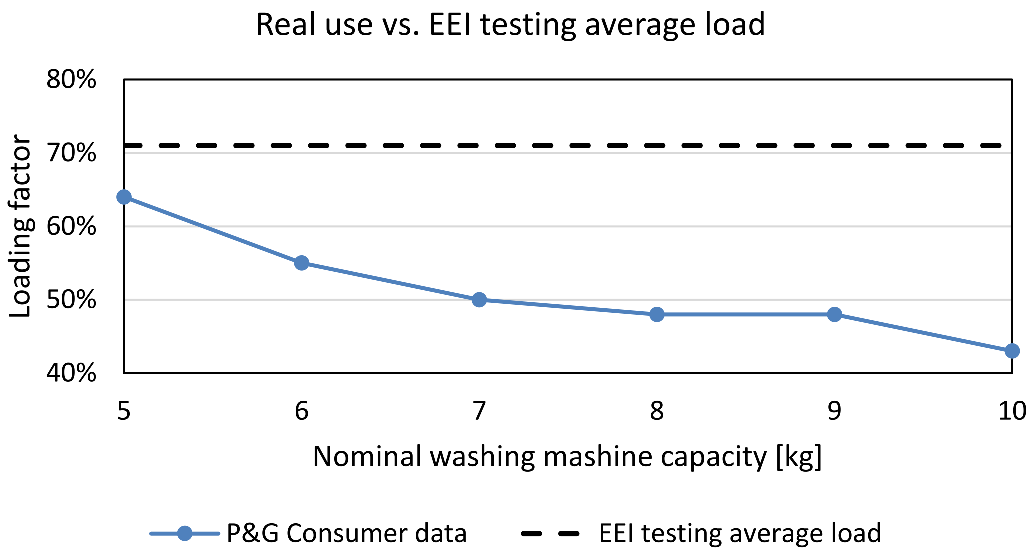

Figure 35: Nominal washing machine rated capacity compared to real use. Loading factor defined as $\frac{\text{Real amount of laundry pr. cycle}}{\text{Recommend maximum load}} \times 100\%$**. *Data source: P&G***

Using the washing machine rated capacity as reference, Figure 35 shows that even the smallest driers with a capacity of 5-6kg, is on average running below the average load of the energy consumption testing procedure. This difference is only increasing with dryers with higher rated capacities. As the figure shows the amount of washed laundry per cycle is not directly proportional to the capacity of the machine.

Users are heavily influenced by the energy efficiency when buying new tumble driers[108], but as the efficiency of the driers are generally higher at larger capacities (especially heat pump driers due to compressor efficiencies in general), users could be biased towards buying driers with higher capacities which are labelled as more energy efficient, although they in real life conditions – due to part load operations – may not be.

The current testing procedures at full and half load conditions can hence be used as a comparative tool between products but is unlikely to represent the real annual energy consumption for the average user, and less so in the future with foreseen increasingly large capacity driers on the market. Changing the testing procedure to reflect the real use, could potentially reverse the trend of manufactures producing unnecessary large units, and emphasize the importance of having driers which can differentiate between being fully loaded and being almost empty.

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[108] PWC: Ecodesign of Laundry Dryers, Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16, Final Report, March 2009, fig. 68.

The annual energy consumption is currently based on 160 cycles/year. As stated in section 3.2, this might not be representative, as the amount of drying done in tumble driers has lowered. Using the average number of drying cycles/week/household of 1.7 / 2.4 for summer and winter times respectively, this gives an average of 107 cycles/year.

3.1.3 Impacts of tumble driers on secondary energy systems

During the use phase, tumble drier types affect the room which the drier is located in, but the effect happens to different extents depending on the tumble drier type. As the drying process is done at elevated temperatures, heat transfer through convection to the room is to be assumed for all types, depending on the amount of insulation present in the drier. For non-air-vented driers, leakage of humid air is also to be expected at varying degrees. The net energy contribution to the secondary system (inhouse climate) depends on whether the drier is located in a heated room or not. 59% of existing tumble driers were in 2018 located in heated rooms[93].

Besides raw heat, moisture is leaked to the room due to non-perfect condensation processes. The air-vented driers do not have this problem, as all moisture is vented to the outside environment. The leaking moisture can in severe cases lead to structural damage and/or mould[109], especially if the drier is situated in small non-heated rooms where the moisture can condensate to droplets on cold walls. If placed in a heated room, the requirements for increased ventilation would naturally add to the energy consumption of the local space heating systems. Driers with heating elements have generally lower condensation efficiency compared to driers with heat pumps: 91% of heat pump driers sold in 2016 had condensation efficiency labels B or better, while only 47.2% of driers with heating elements achieved this[110].

Air-vented driers

Air-vented tumble driers exhaust the hot humid air to the ambient. If the drier is located in a heated room, the drier uses the temperate indoor air as air supply, which after being heated in the machine, is vented to the ambient. This means that cold ambient air (especially in northern Europe) needs to replace the vented air. This air needs to be heated through the space heating system, giving rise to an additional energy consumption related to the use of the tumble drier, if the drier is located in a heated room. The process is visualised in Figure 36.

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[109] https://www.ncbi.nlm.nih.gov/books/NBK143947/
[110] Source: GfK data from 2016

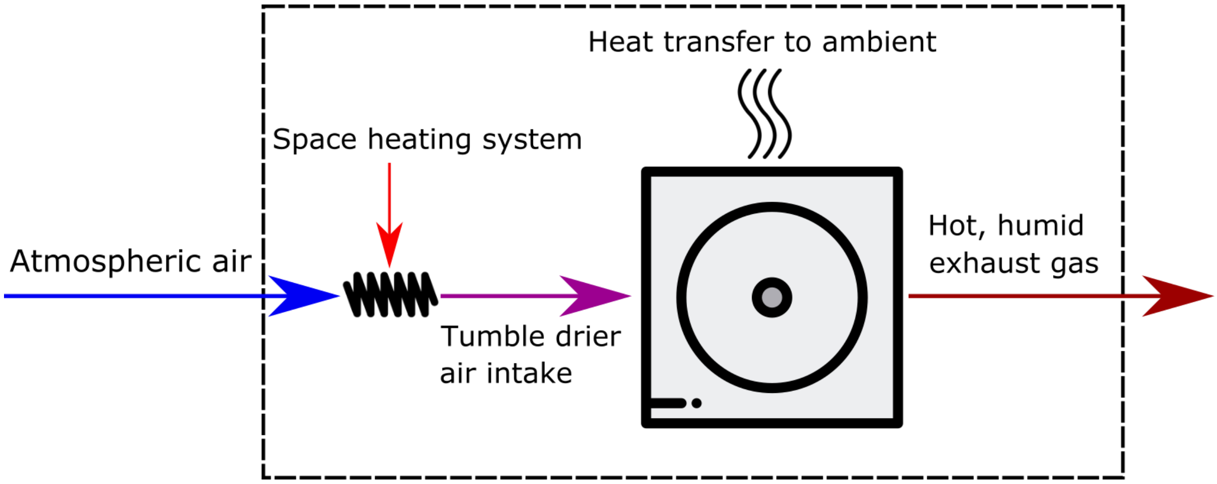

Figure 36: Secondary system impact for air-vented tumble driers

Assuming an average air flow of 120 [m^3/h][111], and a cycle time of 84 minutes[112] the additional energy consumption based on ambient/atmospheric temperatures can be calculated as

$$Q = c_p * \dot{m} * (T_{room} - T_{atmospheric})$$

With c_p being the specific heat capacity of air, and $\dot{m}$ being the air mass flow. The additional energy consumption (in heat) can be seen on Figure 37 in both instantaneous consumption in kW (Left Y-axis), and total consumption for an 84 min cycle in kWh (Right Y-axis)

[111] Preparatory study, p.194
[112] Based on the average value of a weighted cycle time (for full and half loads) for air-vented driers, from APPLIA Model database 2016

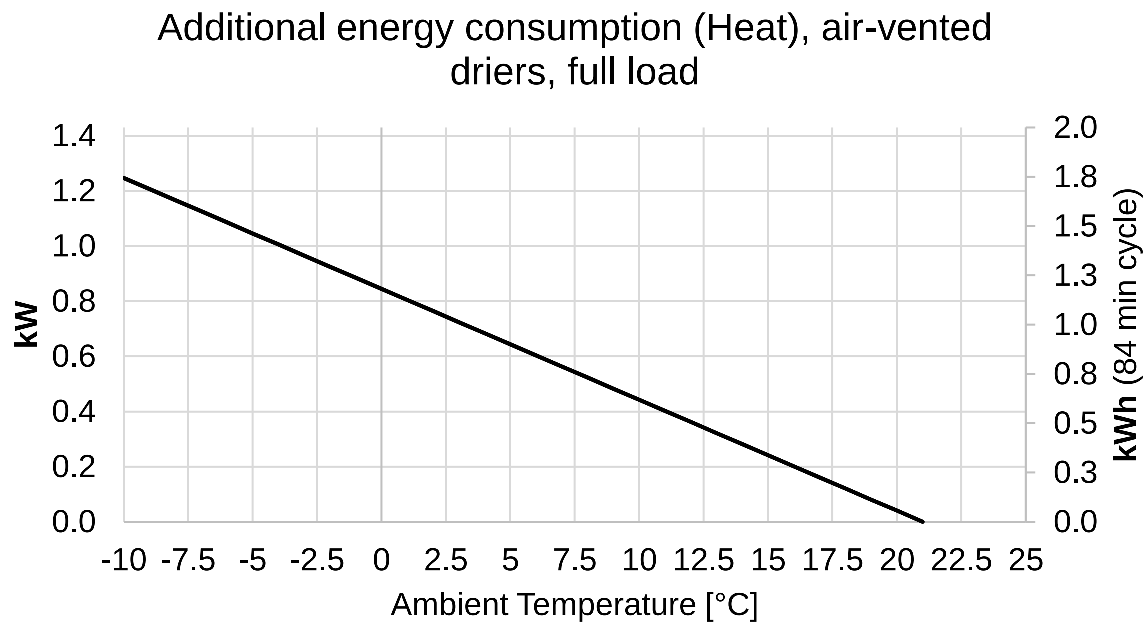

Figure 37: Additional energy consumption for air-vented driers.

Comparing with the SAEc adjustment factor for vented driers (see section 3.1.1), the actual additional energy consumption is heavily influenced by the ambient temperature. Figure 38 shows the percentage increase in total energy consumption for a drier with an energy consumption of 3.4 kWh/cycle[113], assuming the drier is located in a heated room at 21°C. The dotted line is the current penalization/adjust factor for the EEI calculation. It can be seen that especially for colder regions the adjustment factor is insufficient, as the additional energy consumption is generally higher than what the Regulation adjusts for. Furthermore, people tend to generally use their tumble drier more during winter times (see section 3.1.2), which can increase this discrepancy.

The added energy consumption is in the form of heating and not electricity. If for instance a heat pump with a COP[114] of 3 is supplying the inhouse heating, the values should be divided by 3 for the demand of electricity.

[113] Based on the average value of a weighted energy consumption per cycle (for full and half loads) for air-vented driers, from APPLIA Model database 2016

[114] "Coefficient of Performance", denoting the efficiency of the heat pump. A COP of 3 means that for 1kWh of electricity, 3kWh of heating is delivered.

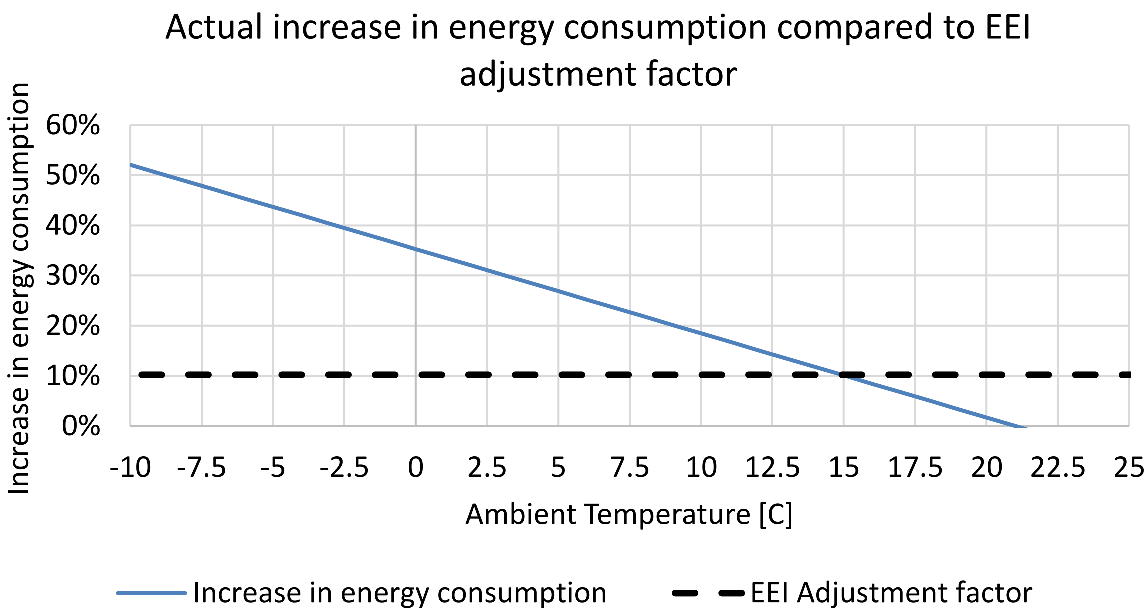

Figure 38: Increase in energy consumption compared to tumble drier with an electric load of 3.4 kWh /cycle.

Condensing driers with heating element

Condensing driers condenses the evaporated moisture (instead of venting it) by using the inhouse/ambient air to condense the water in the hot and humid process air through a heat exchanger. The process is visualised in Figure 39. As the exhaust air in this case is not vented outside, the latent heat from the condensation process is effectively delivered to the inhouse climate, decreasing the energy consumption in the space heating system. The ambient temperature affects the energy consumption of the drier, with a high ambient temperature increasing the energy consumption of the drier due to the dew point being directly related to the temperature. This means that condensing driers should not be placed in small rooms where drier operations could increase local ambient temperature levels.

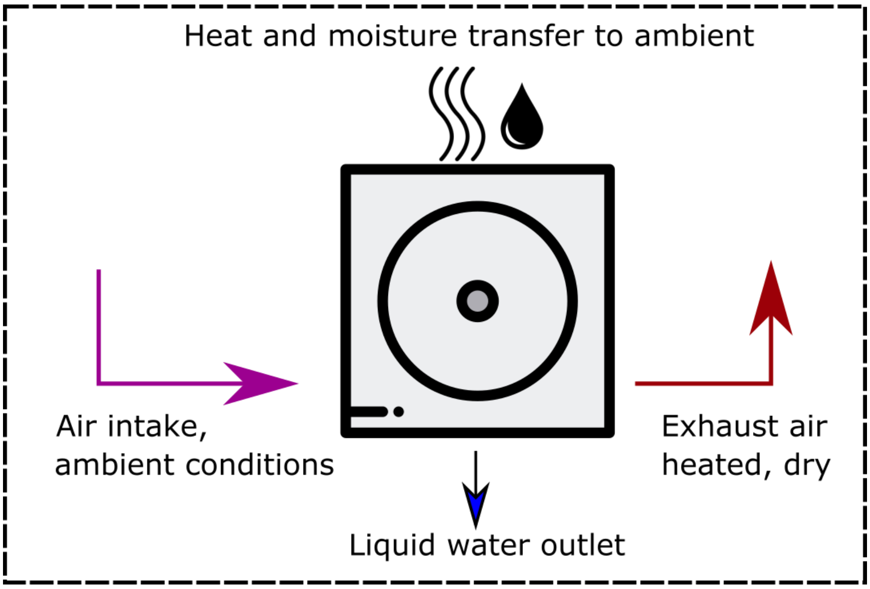

Figure 39: Secondary system impact for condensing driers

Condensing drier with heat pump technology

Driers using heat pump technology use a refrigerant to transfer heat between the drum and the condenser, instead of air. This means that the only impact on secondary systems is heat transfer through convection, and moisture leakage. This allows for a greater flexibility in placing the drier, compared to the other types which have a greater impact on the inhouse climate.

The heat pump circuit does however have a limited temperature working range, as the compressor requires constant cooling. This is done via a secondary air fan, using ambient air. If the ambient temperature is too high, this can cause the compressor to reach critical temperature, forcing it to stop. This can lead to increased cycle times, and increased energy consumption. Heat pump driers should hence also not be places in small rooms without adequate ventilation.

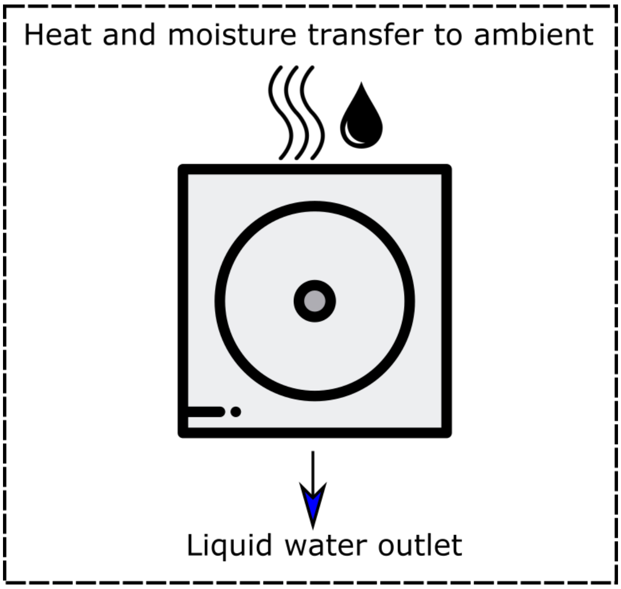

Figure 40: Secondary system impact for driers with heat pump technology

3.2 Consumer behaviour related to product durability and end of life

Aspects concerning the end of life of products that are influenced by consumer behavior are assessed and presented in this section. In particular those that affect the durability, reparability, disassembly and recyclability of tumble driers.

According to the Ecodesign Working Plan 2016-2019[115], special focus to be investigated regarding these aspects are:

- Durability: Minimum lifetime of products or critical components with a view to assess possibilities for extending product lifetime
- Reparability: Availability of spare parts and repair manuals with a view to assess possibilities for design for repair
- Disassembly: Removal of certain components with a view to assess possibilities for increase their reuse and/or recycling at end of life (i.e. by easy removal)
- Recyclability: Identifying materials that hinder recycling with a view to assess possibilities to avoid them in the product design

Only the aspects related to consumer behavior are presented in task 3, particularly regarding durability and reparability. Otherwise they are presented in task 4, as they are related to product design and technologies.

[115] https://ec.europa.eu/energy/sites/ener/files/documents/com_2016_773.en_.pdf

3.2.1 Durability and lifetime

Longer lasting products could have the potential to reduce overall life cycle impacts imposed by appliances. With a longer lifetime the impacts of consumption of raw materials is reduced since the impacts of mining, production, transportation etc. are spread over a longer period of time and displaces the need for new equipment[116]. The product lifetime can be interpreted in numerous ways. Different definitions exist (See Table 25) from other ecodesign studies[117].

Table 25: Different definitions of lifetime

The design lifetime	The behavioural (or social) lifetime	Definition used in this study
Intended lifetime regarding functioning time, the number of functioning cycles, etc., foreseen by the manufacturer when he designs the product, provided that it is used and maintained by the user as intended by the manufacturer. The design lifetime must not be confused with the guarantee period of products, which is a service offered by the manufacturer and fulfils other constraints, namely commercial.	Is defined as the number of years until the device is replaced for other reasons than technical failure or economic unattractiveness. This generally regards social and consumption trends, a product including new feature has been released and is preferred.	The term "lifetime" used in the current study must be understood as the period (i.e. the number of years) during which the appliance is used and consumes electricity ("actual time to disposal"). Therefore, it is a value included between the social lifetime and the design lifetime.

An accurate lifetime can be difficult to determine as many factors can affect the lifetime such as location, hours of operating and maintenance practice. These factors relate to the durability of the appliances, but other factors such as customer requirements and the

[116] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV
[117] https://www.eceee.org/ecodesign/products/airco-ventilation/

desire for new appliances can also affect the lifetime. This tendency is often seen with computers and mobile phones. These products are often replaced or exchanged due to a desire of a newer or better model and not because the product is faulty. The reason for purchasing a new tumble drier was investigated in a recent German study[118] and presented in Table 26.

Table 26: The reason for purchasing a new tumble drier

Year of survey	The old device broke down	The old device was faulty /unreliable	The old device still worked, but I/we wanted a better device
2004	71 %	17 %	12 %
2008	75 %	9 %	16 %
2012	68 %	13 %	19 %

Based on the German study the share of people exchanging a functional machine with a new model is increasing from 12 % in 2004 to 19 % in 2012. This tendency may be due to increased efficiency of tumble driers or new functions such as network capabilities (controlled by e.g. a smartphone) or the purchase of combined washer/driers. For all large household appliances, it should also be noted that the proportion of appliances that were replaced in less than 5 years due to a defect increased from 3.5% to 8.3% between 2004 and 2012.

In the preparatory study the average lifetime used (number of years which the tumble drier is used) was estimated as 10 to 19 years based on stakeholder input and a literature review. These numbers seem to be still valid though it is expected that only very few tumble driers have a lifetime of 19 years while most would have a lifetime up to 14 years maximum[119]. According to a German study[120] the average lifetime of household equipment is falling. The study investigated the lifetime of large household appliances and found that the lifetime has declined from 14.1 years to 13.0 years between 2004 and 2012. This highest reduction in life time was observed for freezers and tumble driers, where the lifetime decreased from 18.2 to 15.5 years and 13.6 to 11.9, respectively. So, the average lifetime of tumble driers used in the current study is reduced to 12 years (definition used in this study, see Table 25). Regarding heat pump condenser driers, the lifetime seemed

[118] Einfluss der Nutzungsdauer von Produkten auf ihre Umweltwirkung: Schaffung einer Informationsgrundlage und Entwicklung von Strategien gegen „Obsoleszenz". Available at: http://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_11_2016_einfluss_der_nutzungsdauer_von_produkten_obsoleszenz.pdf

[119] Assumption confirmed by industry

[120] Einfluss der Nutzungsdauer von Produkten auf ihre Umweltwirkung: Schaffung einer Informationsgrundlage und Entwicklung von Strategien gegen „Obsoleszenz". Available at: http://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_11_2016_einfluss_der_nutzungsdauer_von_produkten_obsoleszenz.pdf

to be reduced with the first models available on the market but today the manufactures have no indication that suggest the heat pump condenser driers have a shorter lifetime than other types of tumble driers. According to manufactures tumble dries are tested with a durability test which ensures a lifetime that fits with the brand of the tumble drier.

The experienced lifetime of tumble driers are investigated by APPLiA and the results of the survey are presented in

Figure 41.

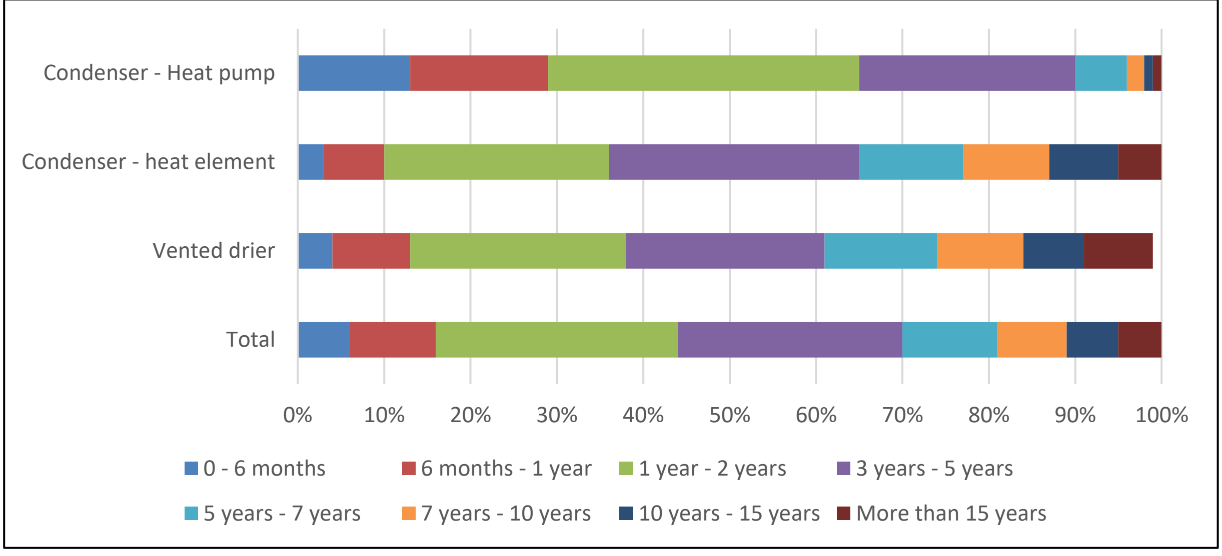

Figure 41: Age of tumble dryer[121]

Based on the

Figure 41, it seems like condenser heat pump driers have lower lifetime compared to other types of driers, but this is not considered to be the case. Condenser heat pump driers are gaining market shares and are a relatively new technology why most of these driers are below 3 years old. It should be noted that a few of the condenser – heat pump driers are above 10 years old.

3.2.2 Repairability and maintenance

A way to improve the lifetime of household appliances is to design products with more possibilities of repair so it is more affordable for the consumers to repair than exchange appliances. Currently are repair and maintenance expected to be done by professionals and in some cases by the end-user. If the repair is done by professionals the cost of repair

[121] APPLiA and InSites Consulting. (2018). Tumble dryer usage and attitudes: A survey in 12 European countries (not publicly available). Draft version.

is constituted of the labour costs and the cost of the spare parts, which means that the affordability of repair is very much dependent on the labour costs

Based on labour cost (presented in **Figure 32**) the amount of repair by professionals is expected to be low in northern countries and higher in southern and south-eastern countries. Another important factor is also the age of the equipment. At end-of-life (above 9-10 years) tumble driers are probably too expensive to repair compared to the price of a new model because new models are assumed to be more efficient or at least it is possible to get a new tumble drier with the same specifications at a low price. Furthermore, a new model is also expected to be more efficient so that the total cost of ownership is lower for the new model compared to repairing the old one an extending the lifetime. This balance is dependent on the energy consumption and price of a new model and the cost of repair. The consumer behaviour and likeliness for repair was investigated in the preparatory study and found that approximately 35 % of the consumers were definitely ready to repair their tumble driers if needed.

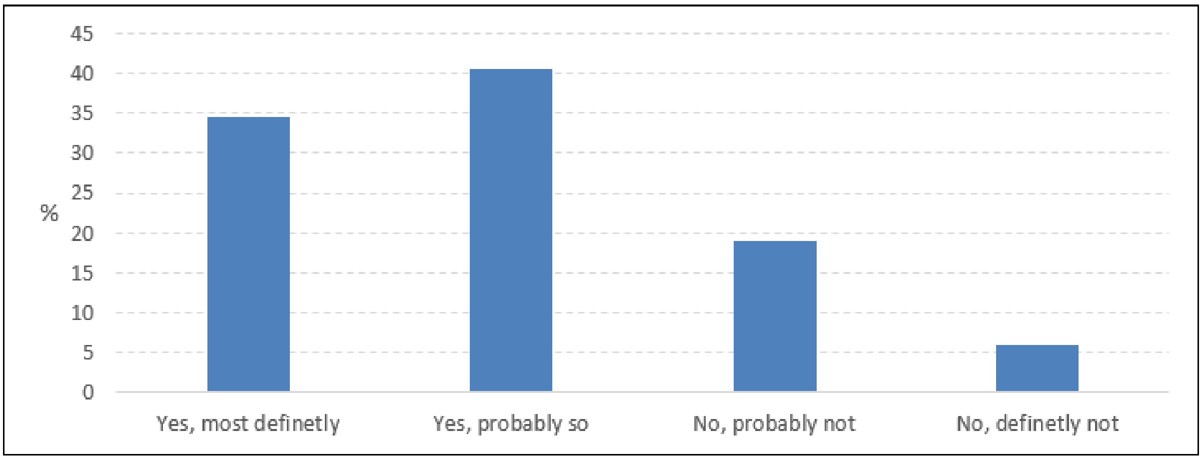

Figure 42: Envisaged reparation of tumble driers (results of survey conducted as part of the preparatory study)

These numbers are still thought to be representative to the current situation despite the increased tendency to replace functioning machines as many tutorials towards repairing and troubleshooting are available online[122]. Though, some manufactures have expressed concern regarding any regulatory measures that promote self-repair due to safety reasons. Instead, they believe it is more important to ease the maintenance of tumble driers. APPLiA have investigated the share of consumers that have experienced technical issues. The result from their survey is presented in Figure 43.

[122] E.g. https://www.partselect.com/Repair/Dryer/ , http://www.ukwhitegoods.co.uk/help/fix-it-yourself/tumble-dryer-self-help and https://www.ifixit.com/Device/Dryer

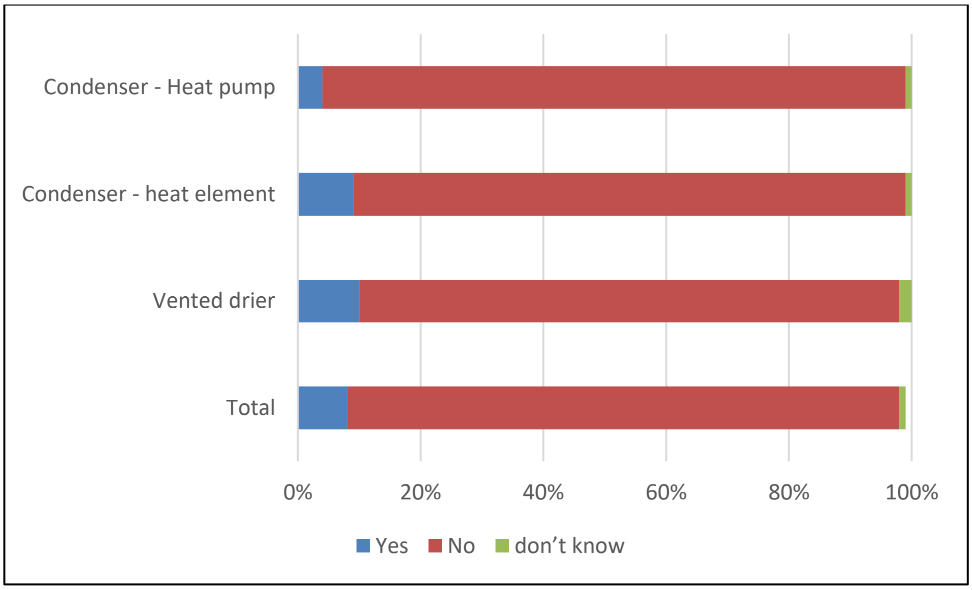

Figure 43: Experienced technical issues[123]

Based on the results from the survey performed by APPLiA it seems like most tumble driers are durable since less than 10 % of the consumers have experienced technical issues. Air-vented -heat element driers are most likely to experience technical issues (10 % of the consumers) while condenser – heat pump driers seems durable (only 4 % of the consumers have experienced technical issues). This tendency could very well be due to the age of appliances where condenser heat pump driers are mostly new appliances on the market (see

Figure 41)

The maintenance of tumble driers is assumed to be performed by the end-user on a regular basis. This maintenance practice can include the following elements (see Table 27). How often the filters and condensation unit are cleaned in real life are investigated by APPLiA and presented in Table 28.

[123] APPLiA and InSites Consulting. (2018). Tumble dryer usage and attitudes: A survey in 12 European countries (not publicly available). Draft version.

Table 27: Maintenance practice for different tumble driers

Maintenance practice	Condenser – heat element	Condenser – heat pump	Air-vented – heat element	Air-vented - gas fired	Remarks
Option 1- Clean the lint filter	X	X	X	X	
Option 2 – Empty the condensate box	X	X			Condenser drier can also be connected to the drain, then it is not needed to empty
Option 3 – Consumer to clean the heat exchanger	X	X (some of them)			
Option 4 – Cleaning the additional lint filter		X			
Option 5 – Cleaning the filter of the condensate box	X	X			
Option 6 – Cleaning the exhaust duct			X	X	
Option 7 - Cleaning the door gasket	X	X	X	X	
Option 8 – Clean the sensor	X	X	X	X	Not needed for non-automatic driers

Table 28: Real life maintenance practice[124]

Clean lint filter	
Every time after I use my tumble dryer	45%
Every week	17%
Every month	18%
Every 2 to 6 months	12%
Every year	3%
When the 'clean filter' indicator goes off (switches on)	4%
Never	1%

Clean other filters	
Every time after I use my tumble dryer	15%
Every week	10%
Every month	20%
Every 2 to 6 months	17%
Every year	4%
When the 'clean filter' indicator switches on	7%
Never	2%
There are no additional filters I am aware of	25%

Clean condensation unit	
After every drying cycle	29%
Roughly after 3 drying cycles	15%
Between 3-10 cycles	21%
Less frequent than once every 10 drying cycles	18%
I don't know	11%
Never	6%

[124] APPLiA and InSites Consulting. (2018). Tumble dryer usage and attitudes: A survey in 12 European countries (not publicly available). Draft version.

The majority of the consumers seems to regular maintain their tumble driers, though a few state that they never clean filters and the condensation unit, in spite they should be cleaned. These driers are subject to premature failure, increased energy consumption and increase duration of the drying process.

If the lifetime of tumble driers is decreasing, it is important to consider the possible trade-offs between resource efficiency and energy efficiency. A WRAP study from 2011 on washing machines indicated that it was beneficial to replace at the time of the study a C-labelled washing machine with an A+ or A++ immediately after purchasing the product with regard to most environmental impact categories (including energy consumption and CO_2-emissions), despite the impacts of producing a new machine[125]. Tumble driers have many similarities with washing machines and it is also assumed that it is beneficial to replace poorly labelled tumble driers with new and efficient models. With time it is assumed that tumble driers will reach a level of energy efficiency that limits further improvements which means that an improved (longer) lifetime would be beneficial.

A recent study on the impacts of increased reparability[126] concluded that simple measures could have neutral to positive impact on the environment, but with some clear gains of resources. The study assessed the environmental impact on four different measures related to reparability. These four measures are briefly described below:

- Option 1 – Measures to ensure provision of information to consumers on possibilities to repair the product
- Option 2 – Measures to ensure provision of technical information to facilitate repair to professionals
- Option 3 – Measures for the provision of technical information to consumers to facilitate simple self-repairs
- Option 4 - Measures to enable an easier dismantling of products

These options are connected with a range of assumption but common for all options is their ability in some degree to support the ideas of the circular economy and stimulate more repair of products and prolong the lifetime. The impacts on the energy consumption, emission of CO_2-eq and consumption of resources (used for the production of appliances and spare parts) of the four measures are presented in Table 29. Note that the baseline is described as:

[125] http://www.wrap.org.uk/sites/files/wrap/Technical%20report%20Washing%20machine%20LCA_2011.pdf
[126] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.

"The baseline corresponds to the business as usual scenario where a new product is bought when the previous fails unless it is repaired according to the current repair rates. Products are replaced by new more efficient ones at the end-of-life. A certain share of the products at the end-of-life is repaired and changes ownership. Disposed products are treated as waste with some materials being recycled and other materials landfilled or incinerated."

Please note that the results mostly can be used as an indicator to show whether each measure has a negative, neutral or positive impact on the environment.

Table 29: Impact of different measures to increase the reparability

Washing machines						
	Baseline		Option 1	Option 2	Option 3	Option 4
Energy	7,173.9 mil. GJ	Min	-0.1%	-0.1%	0%	-0.1%
		Max	-0.3%	-0.3%	0%	-0.5%
Emission of CO_2-eq	1319.4 mil. tonnes	Min	0%	0%	0%	0%
		Max	0%	-0.1%	0%	-0.1%
Resource consumption	26.4 mil. tonnes	Min	-0.1%	-0.1%	0%	-0.2%
		Max	-0.4%	-0.3%	0%	-0.7%

The findings in the study indicates that option 1, option 2 and option 4 all have a positive effect on the environment with reductions in energy consumption and resource consumption. Option 2 and option 4 may also have a positive effect on the emission of CO_2-eq. Option 3 which is the measure for the provision of technical information to consumers to facilitate simple self-repairs has neutral impact, as the consumers are considered to perform only simpler repairs.

Availability of spare parts

Spare parts are available on the internet from manufacturers[127] and third part companies offering spare parts and sometimes also a repair service. From a quick survey on the internet it seems like critical spare parts are available from a large range of different manufactures but the availability in time is difficult to quantify. Critical spare parts are the parts that are important for the function of the tumble driers. Based on a survey and inputs from manufactures the critical spare parts are presented in Table 30.

[127] E.g. https://www.miele.co.uk/domestic/spare-parts-and-accessories-383.htm

Table 30: Critical components and assessment of the ease of replacement

Component	Is the component easy to replace?
Pumps	Depending on brand and location of the pump
Fans	Depending on brand as some states it is difficult to replace while other states it is easy for a professional
Motor(s)	Depending on brand as some states it is difficult to replace while other states it is easy for a professional
Electronics	Depending on brand as some states it is difficult to replace while other states it is easy for a professional
Compressor	Difficult to replace or no access
Heat exchanger	No access

Regarding the availability of spare parts, it is assumed that most manufactures provide spare parts but the availability in time can differ from the different manufactures. A stakeholder has indicated that they supply spare parts for at least 10 years which seems to be adequate compared with the assumed lifetime.

Spare parts are crucial to ensure a long lifetime of products and are needed to prevent premature failure. The most obvious impact of spare part availability for all brands (budget to premium) is an increase in the number of repairs.

The study on the impacts of increased reparability[128] also investigated the impact of measures to ensure supply of spare parts for at least a certain amount of years and the combination of different options, which are:

- Option 5 – Measures to ensure availability of spare parts for at least a certain amount of years from the time that production ceases of the specific models
- Option 6 – Combination of option 5 and option 2 presented in the above section about repair and maintenance (measures to ensure provision of technical information to facilitate repair to professionals)
- Option 7 – Combination of scenarios 5 & 4 presented in the above section about repair and maintenance (measures to enable an easier dismantling of products)

These options are connected with a range of assumptions but common for all options is their ability in some degree to support the ideas of the circular economy and stimulate more repair of products and prolong life time. The impacts on the energy consumption,

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[128] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.

emission of CO_2-eq and consumption of resources of the four measures are presented in Table 31.

Please note that the results mostly can be used as an indicator to show whether each measure have a negative, neutral or positive impact on the environment.

Table 31: Impact of different measures to increase the reparability – availability of spare parts

Washing machines					
	Baseline		**Option 5**	**Option O6**	**Option O7**
Energy	7,173.9 mil. GJ	Min	-0.2%	-0.2%	-0.2%
		Max	-0.7%	-0.8%	-1%
Emission of CO_2-eq	1319.4 mil. tonnes	Min	0%	0%	0%
		Max	-0.1%	-0.2%	-0.2%
Resource consumption	26.4 mil. tonnes	Min	-0.2%	-0.3%	-0.3%
		Max	-0.9%	-1%	-1.2%

In Figure 44 all options are compared with each other and it seems like that the most beneficial single option is the measure to ensure spare parts for a certain amount and years (Option 5). However, both of the combined options (option 6 and option 7) may have even greater impact (positive impact) on the environment. It should be noted that both of these combined options also include option 5.

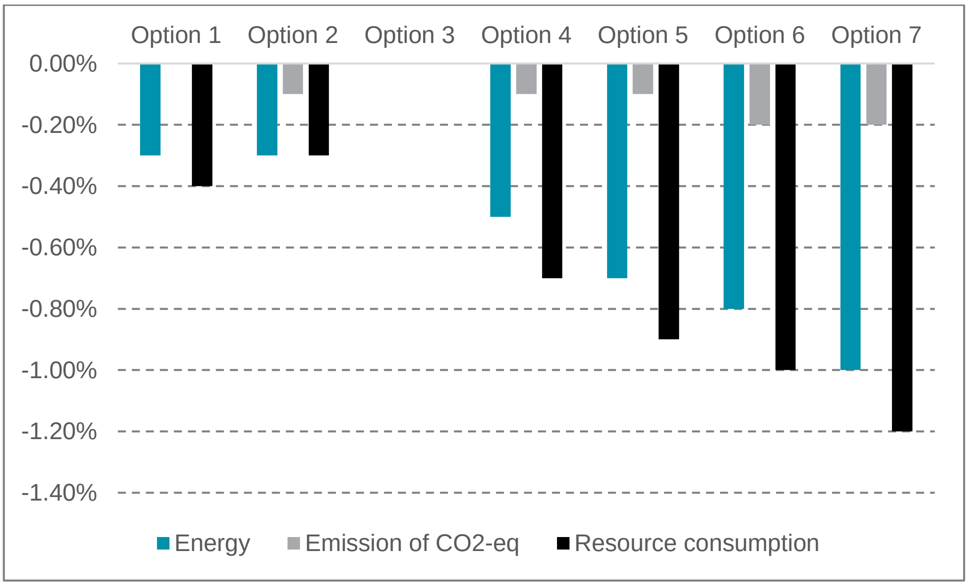

Figure 44: Impact of all options towards increased reparability

Different approaches can be implemented towards improved reparability, reusability, recyclability, dismantlability and a prolonged lifetime as discussed above. The lifetime is not solely dependent on break downs or malfunctioning components as more consumers are replacing functioning appliances due to a desire for an improved model with e.g. improved efficiency.

3.2.3 Best practice in sustainable use

Sustainable product use can minimize the energy consumption of tumble driers and a few best practices are listed in this section.

As discussed previously, it is important to purchase a properly sized tumble drier and not buying it oversized. This may result in operation at part load, which increases the specific energy consumption (see section 3.1.1). According to presented data in this section, consumers load the machines similarly regardless of the capacity. Consumers may buy large appliances for the convenience if they want to dry large blankets resulting in operation with a low load most of the year. It is also important to spin the clothes properly in the washing machine as it is less energy intensive to spin the clothes in the washing machine than to dry it in the tumble drier.

Other important aspects may be:

- Proper maintenance of the appliance and specially to clean the lint filter between uses. This will allow the correct air flow through the appliance.
- Use a lower heat setting than, e.g. cupboard dry, if the clothes have anyway to be ironed afterwards.
- Use the moisture sensor if it is available to avoid over drying.

3.2.4 Collection rates at households/other users

Following the framework of the WEEE Directive, tumble dries must be collected at end-of-life and sent to suited facilities for reprocessing. Illegal trade and sales of scrap challenge the collection rate for some product categories. The statistics from Eurostat present products placed on the market and waste collected for large household equipment[129]. No statistics are available specifically for tumble dries collected so the actual collection rate is difficult to quantify.

From 2019 onwards, the minimum collection rate to be achieved annually shall be 65% of the average weight of Electrical and Electronic Equipment (EEE) placed on the market in the three preceding years in each Member State, or alternatively 85% of Waste Electrical and Electronic Equipment (WEEE) generated on the territory of that Member State[130]. Table 32 shows the collection rate for large household appliances calculated based on the WEEE

[129] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselee&lang=en
[130] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0019&from=EN

collected in 2014 and the average weight of EEE placed on the market in the three preceding years.

Table 32: Calculated collection rate of large household equipment in Europe, 2014

	Average EEE put on the market 2011-2013	WEEE collected 2014	Collection rate
Austria	77,662	31,199	40%
Belgium	107,115	50,781	47%
Bulgaria	38,664	30,286	78%
Croatia	23,445	5,275	22%
Cyprus	8,350	1,222	15%
Czech Republic	72,575	27,828	38%
Denmark	65,210	32,890	50%
Estonia	8,223	1,854	23%
Finland	71,690	33,917	47%
France	918,570	292,730	32%
Germany	748,121	239,662	32%
Greece	86,162	27,317	32%
Hungary	45,004	28,682	64%
Iceland	3,305	1,696	51%
Ireland	38,306	23,797	62%
Italy	501,190	142,666	28%
Latvia	8,728	2,490	29%
Liechtenstein	36	75	208%
Lithuania	15,352	12,429	81%
Luxembourg	4,690	2,586	55%
Malta	6,206	971	16%
Netherlands	112,119	64,496	58%
Norway	70,451	49,402	70%
Poland	244,980	81,082	33%
Portugal	73,738	33,154	45%
Romania	75,341	20,465	27%
Slovakia	25,087	11,590	46%
Slovenia	17,030	4,535	27%
Spain	355,992	101,827	29%
Sweden	107,447	71,306	66%
United Kingdom	708,172	296,520	42%
Total	4,638,962	1,724,730	37%

The average collection rate for large household equipment at EU level was just below 40 % in 2014. This value should be improved to 65 % in 2019 according to EU targets. The low collection rate of products cannot be directly addressed in the Ecodesign Regulation but should be addressed by each Member State regarding their obligations with regard to the WEEE Directive.

3.2.5 Conclusion on consumer behaviour related to product durability and end-of-life

In general, the average lifetime of household equipment is falling, and the initial service life has declined from 14.1 years to 13.0 years between 2004 and 2012 of large household appliances. This highest reduction in life time was observed for freezers and tumble driers which decreased from 18.2 to 15.5 years and 13.6 to 11.9, respectively. So the average lifetime of tumble driers in the current study is reduced to 12 years. Regarding heat pump condenser driers, the lifetime seemed to be reduced for the first models available on the market but today the manufactures have no indication to suggest that heat pump condenser driers have a shorter life time than other types of tumble driers. Based on a consumer study performed by APPLiA the durability of condenser heat pump driers is not expected to present particular issues and the consumers rarely experience any technical failures.

A way to improve the lifetime of household appliances is to design products with more possibilities of repair so it is more affordable for the consumers to repair than exchange appliances. Currently the repair and maintenance practices are expected to be done by professionals and in some cases by the end user. Based on the Deloitte study it seems like the following options have a positive effect on the environment:

- Measures to ensure provision of information to consumers on possibilities to repair the product
- Measures to ensure provision of technical information to facilitate repair to professionals
- Measures to enable an easier dismantling of products
- Measures to ensure availability of spare parts for at least a certain amount of years from the time that production ceases of the specific models
- Different combination of the above-mentioned options

The option with measures to facilitate simple self-repairs was considered to have a neutral effect because of the limitation in repair procedures that can be performed by the consumers.

3.3 Local infrastructure

3.3.1 Electricity

The power sector is in a transition state moving from fossil fuels to renewable energy. The origin of the electricity is a very important factor to consider both regarding the environmental impact by using a tumble drier and how it may affect the consumer behaviour (smart grid functionalities). Within the EU there are a number of renewable energy targets for 2020 set out in the EU's Renewable Energy Directive[131]. The overall target within the EU is 20% of final energy consumption from renewable sources. The final energy consumption is the total energy consumed by end-users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself[132]. To achieve this goal of 20 % from renewable sources the different EU countries have committed to set their own individual goal ranging from 10 % in Malta to 49% in Sweden. In 2015 the share of renewable energy was almost 17%[133].

The electricity consumption is a major part of the final energy consumption and the electricity mix is highly relevant for quantifying the environmental impacts of tumble driers at EU-level. The electricity mix in 2015 is presented in Figure 45.

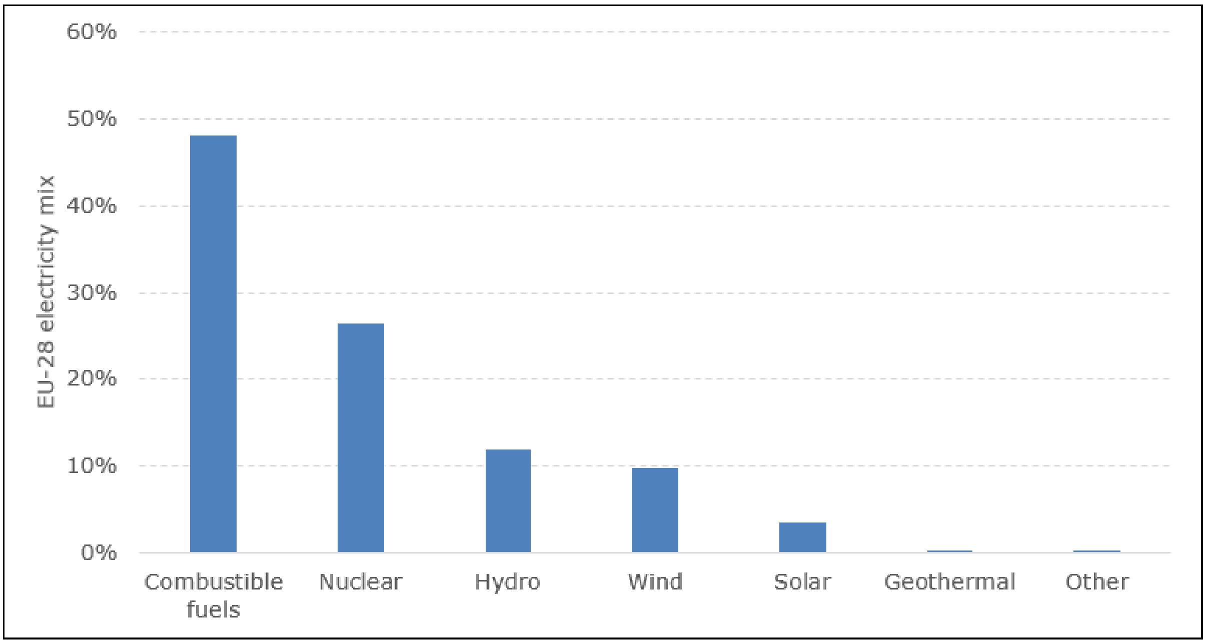

Figure 45: Net electricity generation, EU-28, 2015 (% of total, based on GWh)[134]

Almost half of the electricity generation still originates from combustible fuels (such as natural gas, coal and oil) and renewable energy sources only constitutes about 25 % of the electricity generation in 2015.

The reliability of the electricity grid could be in some degree affected by the transition to a renewable energy system. With more renewable energy in the system new challenges occur e.g. with excess production of wind energy and the two-directional transfer of energy

[131] https://ec.europa.eu/energy/en/topics/renewable-energy
[132] http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Final_energy_consumption
[133] http://ec.europa.eu/eurostat/documents/2995521/7905983/8-14032017-BP-EN.pdf/af8b4671-fb2a-477b-b7cf-d9a28cb8beea
[134] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Net_electricity_generation,_EU-28,_2015_(%25_of_total,_based_on_GWh)_YB17.png

(e.g. electric cars that can supply electricity to the grid when it is not in use). Due to technological development, the reliability of the electricity supply in many EU countries is ensured via the expansion of the electricity grid to distribute renewable energy. The quality of the electricity grid in Europe is considered to be high and among the best in the world. Every year the World Economic Forum releases a Global Energy Architecture Performance Index report. The report is ranking the different countries on their ability to deliver secure, affordable, sustainable energy. In recent years European countries have dominated the top spots (see Table 33)[135].

Table 33: Top spots of the global Energy Architecture Performance Index report

Country	2017 score	Economic growth and development	Environmental sustainability	Energy access and security
Switzerland	0.8	0.74	0.77	0.88
Norway	0.79	0.67	0.75	0.95
Sweden	0.78	0.63	0.8	0.9
Denmark	0.77	0.69	0.71	0.91
France	0.77	0.62	0.81	0.88
Austria	0.76	0.67	0.74	0.88
Spain	0.75	0.65	0.73	0.87
Colombia	0.75	0.73	0.68	0.83
New Zealand	0.75	0.59	0.75	0.9
Uruguay	0.74	0.69	0.71	0.82

The consumer behaviour might affect the electricity system in some countries since the use of tumble driers are assumed to be more common in the winter period where the monthly energy consumption is higher for most countries. In Table 34 are the monthly electricity consumption presented for most of the EU countries[136]. Note that the peak consumption is marked with red and the lowest consumption marked with blue.

[135] https://www.weforum.org/reports/global-energy-architecture-performance-index-report-2017
[136] Data provided by ENTSO-E

Table 34: Monthly electricity consumption

MONTHLY CONSUMPTION (IN GWh)													
Country	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Total**
Austria	6498	5984	6203	5542	5468	5376	5588	5436	5271	5900	6005	6234	69505
Belgium	8057	7312	7653	6940	6795	6657	6548	6609	6731	7221	7202	7284	85009
Bulgaria	3455	3068	3111	2639	2404	2363	2611	2537	2416	2703	2766	3171	33244
Cyprus	368	364	338	283	314	343	452	495	441	351	298	358	4405
Czech Republic	6019	5584	5774	5200	4972	4818	4859	4641	4865	5509	5553	5624	63418
Germany	48952	45608	46179	40889	39607	39875	41470	39824	40911	45723	46280	45289	520607
Denmark	3188	2909	2916	2306	2648	2907	2556	2692	2697	1943	2555	3113	32430
Estonia	816	719	743	679	634	573	574	593	624	719	714	751	8139
Spain	23883	22048	22279	19837	21016	21614	24972	22341	20897	20964	20985	22069	262905
Finland	8437	7336	7645	6756	6268	5838	5941	6008	6118	7138	7279	7730	82494
France	52475	48579	45707	36847	33873	33225	34887	31582	33483	39167	40985	44593	475403
United Kingdom	32243	29083	31380	26097	26044	24327	24569	24361	25082	28320	30380	30768	332654
Greece	4829	4299	4504	3772	3823	3965	4855	4687	4086	3835	3895	4610	51160
Croatia	1538	1429	1461	1314	1292	1288	1573	1494	1336	1351	1369	1539	16984
Hungary	3629	3316	3507	3218	3209	3249	3484	3342	3313	3507	3490	3491	40755
Ireland	2498	2279	2397	2154	2192	2055	2100	2087	2120	2276	2353	2445	26956
Italy	26786	24948	26793	24169	25027	26328	31970	24458	26449	25907	25675	25818	314328
Lithuania	1005	891	920	873	862	825	846	863	866	955	958	995	10859
Luxembourg	574	538	579	516	497	503	542	512	492	554	547	514	6368
Latvia	692	616	635	589	571	522	549	568	562	625	626	654	7209
Netherlands	10343	9183	9588	8741	8881	8823	9191	9049	9149	9685	9763	10119	112515
Poland	13546	12327	13116	12060	12011	11716	12333	12295	12099	13257	13066	13254	151080
Portugal	4713	4232	4167	3727	3939	3964	4280	3907	3883	3987	3977	4189	48965
Romania	5023	4598	4791	4435	4258	4202	4636	4398	4266	4665	4634	4877	54783
Sweden	14100	12610	12851	10967	10494	9602	8907	9561	9888	11578	12242	13130	135930
Slovenia	1233	1130	1178	1067	1092	1088	1149	1073	1099	1175	1164	1199	13647
Slovakia	2470	2277	2393	2194	2157	2115	2191	2136	2128	2360	2350	2405	27176

Only a few southern countries have their peak consumption in July and August and the majority of the countries have their peak consumption in January. The lowest monthly electricity consumption levels are, for most countries within EU, in June. The hourly load values for a random Wednesday in March 2015 for selected countries are presented in Figure 46.

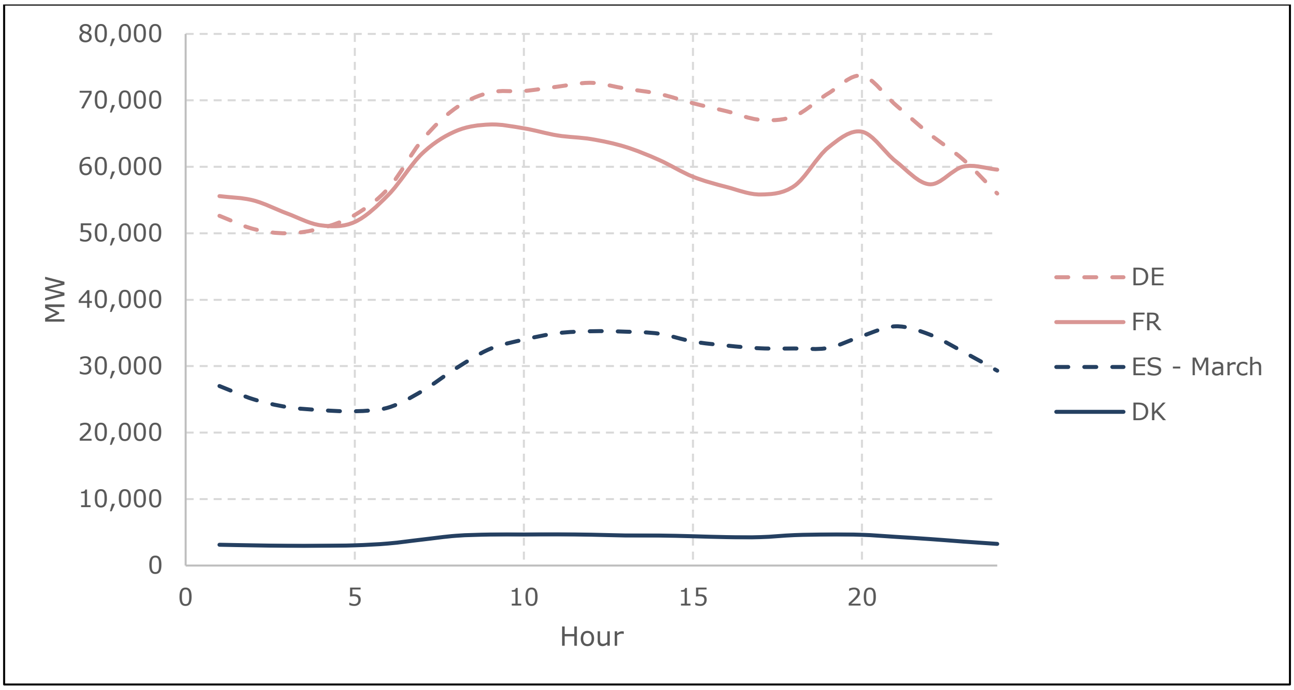

Figure 46: Hourly load values a random day in March

All presented countries have similar hourly load values with two peaks, one in the morning and one in the evening. It is barely visible for Denmark, but this is due to scale of the graph. However, there are small shifts in the peaks. In Denmark, the peaks occur a little earlier than in Spain. The first peak fits well with the start of the workday and the second peak fits with the end of the workday. Between the two peaks there is a falling trend in the energy consumption. The lowest electricity consumption across the different countries is at 5 AM. For most countries, this hourly load curve fits this description of the majority of the days. For months and days with a higher or lower consumption tendency the profile is very similar with more pronounced shifts up or down.

Renewable energy production can vary greatly from hour to hour and day to day. In the future, products that can respond to an external stimulus (e.g. smart appliances), can provide balance and flexibility to the energy system. Though, tumble dries are dependent on washing machines and they need to be operated within a certain time period after the end of the washing cycle to avoid bad odour from the clothes. It is possible to postpone the start of tumble driers a little, but the flexibility of combined washers and driers are assumed to be higher.

3.3.2 Gas

The reliability of the energy system as a whole is high. The values presented consider the entire energy system including the gas system. Nevertheless, the gas supply may be less reliable than the electricity supply due to the high imports of gas from non-EU28 countries. Norway and Russia are major suppliers of gas, and Russia’s supply often goes through transit countries such as Ukraine and Belarus. The gas supply in Europe is roughly described in Figure 47[137] and presents possible shortage in the supply chain.

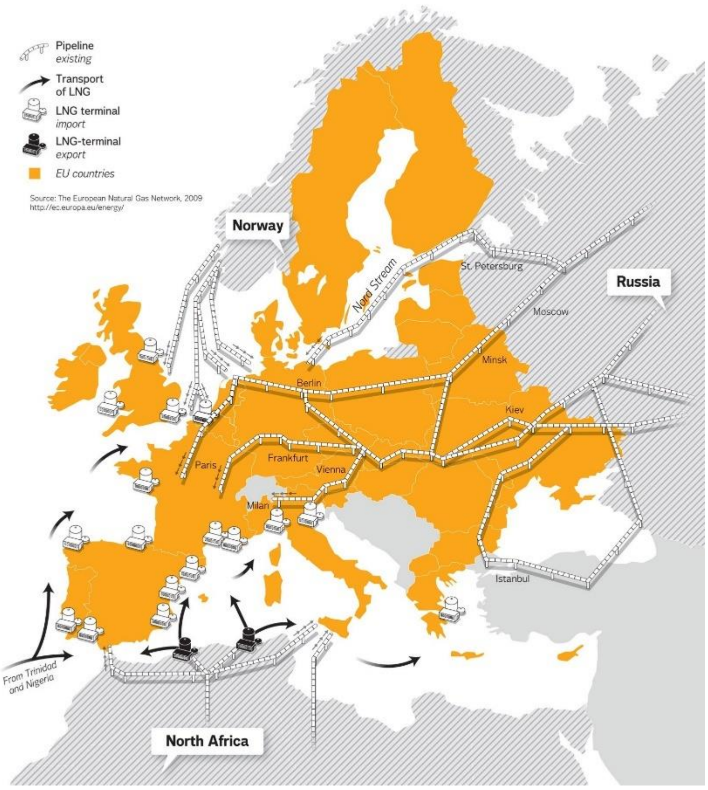

Figure 47: Rough drawing of the transport of gas in Europe

Roughly a quarter of all the energy used in the EU is natural gas, and many EU countries import nearly all their gas and some of these countries are heavily reliant on a single source or a single transport route for the majority of their gas. These countries are more vulnerable to disruptions in their gas supply. Disruptions can be caused by infrastructure failure or political disputes.

To prevent supply disruptions and quickly respond to them if they happen, EU created common standards and indicators to measure serious threats and define how much gas EU countries need to be able to supply to households and other vulnerable consumers. In 2017, a new Regulation regarding the security of the gas supply[138] was introduced. The new Regulation has a number of requirements which e.g. requires the European Network for Transmission System Operators for Gas (ENTSOG) to perform EU-wide gas supply and infrastructure disruption simulation in order to provide a high level overview of the major supply risks for the EU and introduces a solidarity principle (EU countries must help each

[137] https://corporate.vattenfall.com/about-energy/energy-distribution/gas-distribution/
[138] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1938&from=EN

other to always guarantee gas supply to the most vulnerable consumers even in severe gas crisis situations). Such precautions increase the reliability of the gas supply and therefore is the supply of gas assumed to be reliable.

3.4 Verification tolerances

The verification tolerances stated in the Regulations are to be used by market surveillance authorities when testing products to account for uncertainties in the tests and variations in production. The verification tolerances in Table 35 are given in the Regulations.

Table 35: Verification tolerances set out in the Regulations

Test parameter	Unit	Tolerance
Weighted annual energy consumption (AE_c)	kWh/year	6%
Weighted energy consumption (E_t)	kWh	6%
Weighted condensation efficiency (C_t)	%	6%
Weighted programme time (T_t)	Minutes	6%
Power consumption in off mode and left-on mode (P_o and P_l)	W	6% for consumption more than 1.00W. 0.1W for consumption below 1.00W
Duration of the left-on mode (T_l)	Minutes	6%

The verification tolerances are closely related to the tests and the uncertainties of them. As the standardisation group has created very thorough testing procedures and continuously works to refine them, no reasons to increase the tolerances have been found.

The study team is waiting for a round-robin test to be finished by March/April.

4. Technologies

No major technical improvements at product level have emerged on the market for tumble driers since the preparatory study. As seen in task 2, the four main types of tumble driers, air-vented with heating element, air-vented with gas combustion, condensing with heating element and condensing with heat pump still exist. However, very few models of gas-fired tumble driers have been available for sale on the EU market and no major developments in this type of drier has been made in the past 10 years[139]. Gas fired tumble driers represented 0.05% of the total sales from 2013-2016[140].

Concerning technologies, some technologies and/or addons mentioned as available during the preparatory study have been discontinued[141] (see below):

- **Air-vented** driers:
  - Exhaust air recovery.
  - Air-vented drier with heat pump technology.
- **Condensing** driers:
  - External heat source driers.

The Best Available Technology (BAT) from the preparatory study was condensing heat pump driers. Nowadays, these are still presenting the highest energy efficiency. The increase of efficiency of the BAT has been obtained by improving the integrated heat pump and adding more efficient components, instead of introducing a new type of heating technology. Heat pump driers have progressed from having a market penetration rate below 5% during the preparatory study (in 2009), to being the most commonly sold type of tumble drier accounting for 52% of sold units in 2016 (see Table 9). The heat pump drier can hence be considered as the most common tumble drier technology on the current market.

As the working principle of the current available technologies have had no major alterations since the preparatory study, the focus in this task is to look at the different components in the tumble drier, to identify the major developments that have been made.

The tumble drier unit consists of multiple components which can be of different types and qualities. Some are found in all tumble driers types and from these, the following components and their configurations have a major influence on the energy consumption:

  - The motor type and setup

[139] According to input from industry
[140] Source: GfK data
[141] According to desktop research

- The presence of variable speed drives for fans and drum motors
- The controller, including humidity sensor components
- The drum design and sealing method
- The cleanliness of lint filters and heat exchangers

Additionally, for condensing driers:

- Air to air heat exchanger type, material, and size

And furthermore, for heat pump condensing driers

- Compressor size, type and motor

Based on input from industry[142], Table 36 shows a list of the major components and technologies having an impact on the energy efficiency of the drier. Each component/technology and relevant improvement options are described in more details in section 4.1.1.

Table 36: List of components for the average tumble drier.
HP-C = Condensing heat pump drier, HE-C = Condensing heating element drier, HE-V = air-vented heating element drier, GA-V = air-vented gas fired drier.

Tumble drier technology/Component	Average drier on the market	*Relevant for*			
		HP-C	HE-C	HE-V	GA-V
MOTORs					
Motor type setup (one or multiple)	One	x	x	x	x
Motor type (drum)	AC-Induction	x	x	x	x
Motor type (compressor)	AC-Induction	x			
↳ If permanent magnet, has RER	No	x	x	x	x
VSD on motor drum drive	No	x	x	x	x
VSD on motor fans	No	x	x	x	x
VSD on compressor motor	No	x			
CONTROLLER					
Type of automatic controller	Automatic moisture sensor controller (direct way)	x	x	x	x
HEAT EXCHANGER (Air to air)					
Heat exchanger material	Aluminium		x		
Heat exchanger type	Plate-fin		x		
Self-cleaning heat exchangers	No		x		
HEAT EXCHANGER (Refrigerant - air)					
Heat exchanger material	Aluminium fins + copper tubes	x			
Heat exchanger type	Fin-and-tube	x			

[142] Questionnaire sent to APPLiA members on technologies during months February-March 2018

Tumble drier technology/Component	Average drier on the market	*Relevant for*			
		HP-C	**HE-C**	**HE-V**	**GA-V**
Self-cleaning heat exchangers	No	x			
COMPRESSOR					
Compressor size	400-600 W	x			
DRUM					
Drum material	Steel	x	x	x	x
Direct Drive	No	x	x	x	x
Drum leakage	High/Medium	x	x		
USER INTERFACE					
Eco-mode program	No	x	x	x	x
FILTERS[143]					
Anti-clogging design	No	x	x	x	x

4.1.1 Products with standard improvement design options

The following subsections give general descriptions of key components and how improvements for each component can lead to energy efficiency improvements.

Motors for all drier types

The motors used for driving the drum and fans are of different types, from single-phase capacitor run induction motors to synchronous motors, such as brushless DC motors (BLDC). Furthermore, variable speed drives can be used for motors running the drum drive, the fans and/or the compressor (the latter only for heat pump driers).

Synchronous motors, such as BLDC motors, are generally more efficient than traditional asynchronous AC induction motors (both single and three phased)[144]. This is partly because induction motors use current to create electromagnets, where synchronous motors utilize permanent magnets. Synchronous motors are however typically more expensive, and they require a controller (frequency inverter) to be present in the unit.

With the introduction of BLDC motors, the overall motor configuration has changed as well. Whereas in the preparatory study almost every drier used one single motor to drive the drum and the fan for process air and to drive the fan for the condensing air (in condensing driers only) or compressor cooling air (heat pump driers only), some top-class driers nowadays use a smaller BLDC for each of these systems. This can improve the overall efficiency, as it enables the machine to switch individual systems on/off as they are needed.

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[143] Both the primary lint filter, and for the condenser lint filter for HP-C driers without self-cleaning heat exchangers.

[144] http://www.orientalmotor.com/brushless-dc-motors-gear-motors/technology/AC-brushless-brushed-motors.html

Variable Speed Drives for all drier types

The introduction of variable speed drives introduces a range of benefits. They can be placed on each of the before mentioned systems, as well as on the compressor for heat pump driers.

Using a variable speed drive on the heat pump compressor can give major improvements to the efficiency[145], especially with regard to part load operation or when reduced drying temperatures are wanted (for long cycles or delicate fabrics).

A heat pump efficiency is fundamentally linked to the temperature levels in the evaporator and condenser. A large temperature difference results in low efficiency and vice versa. These temperatures, represented as the evaporation and condensation temperature, are the results of multiple parameters, such as pressure ratios, heat exchanger effectivities, and refrigerant flow rate. Larger heat exchangers can sustain a lower temperature difference between the refrigerant and the process air, which improves performance by reducing the difference between the evaporation and condensation temperatures.

When lowering the flow rate by reducing the speed of the compressor, the heat flux from the condenser to the process air is lowered. As the size of the heat exchangers however remain constant, the temperature difference can be lowered and thus – as mentioned before – increase the performance. Another major benefit is the reduction of the energy consumption associated with start-up of the heat pump unit, which can be substantial at part load operations, as the heat pump unit can run continuously instead of start-stop operation.

Controller for all drier types

99% of all commercially available driers are equipped with a controller that automatically turns off the drier when a specific moisture content is reached in the laundry[146]. This is done either by directly measuring the moisture level through a conductivity sensor in contact with the laundry, or indirectly by measuring the humidity level in the process air. Accurately monitoring the moisture content is key to an efficient drying process, as an inaccurate measurement can lead to either under- or over drying the laundry, either resulting in poor drying performance, or an increased energy consumption.

Eco-mode programs are available on some driers, where an increased cycle time can result in lower energy consumptions. This is advantageous if the cycle time is unimportant for

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[145] http://www.rehva.eu/publications-and-resources/rehva-journal/2012/052012/capacity-control-of-heat-pumps-full-version.html

[146] APPLIA Model database 2016

the customer. The increased cycle time is done by lowering the drying temperature by throttling the heat pump unit or the heating element.

Heat exchangers for condensing driers

Two different types of heat exchangers exist. For heating element condensing driers, a condenser exists which condenses the water vapor in the process air, by parsing it through a heat exchanger cooled by the outside air via a fan. This is hence an air-to-air heat exchanger.

For heat pump condensing driers, an additional heat exchanger exists between the process air and the refrigerant, which is used to deliver the heat from the heat pump cycle to the process-air. It acts as a condensing unit for the refrigerant and is thus a liquid/air-to-air heat exchanger.

Furthermore, the process-air condensing heat exchanger uses the heat pump cycle instead of outside air to condense the water. It acts as an evaporator unit for the heat pump cycle and is thus also a liquid/air-to-air heat exchanger.

The efficiency of the heat exchangers plays an important role with regard to the energy consumption of the driers – especially the heat pump unit, as more efficient heat exchangers can reduce the pressure levels in the heat pump cycle. For the heating element condensing driers, a more efficient heat exchanger increases the condensation rate.

Common for both types, is that the thermal conductivity in the material used is directly linked to the efficiency. Copper is a commonly used material for heat exchangers but is also expensive. Other options are aluminium, nickel alloys, or even stainless steel – all of which are cheaper, but also have a lower thermal conductivity and thus comparably lower effectiveness.

Compressor for heat pump condensing driers

In heat pump driers, the size of the compressor (i.e. pressure ratio and volume flow) is directly linked to the maximum achievable temperature of the process air. Larger compressors can hence reduce drying times but are also more expensive. Larger compressors are thus seen in some top models, which add shorter cycle times as a feature.

As the compressor is the component using the largest amount of energy, it is vital that the compressor itself is efficient. The whole heat pump circuit (compressor, heat exchangers, refrigerant) can however only run efficient if all components are optimised with respects to each other and the goal of which the optimisation process is revolved around, whether it is to run efficient, fast, or a combination hereof. For instance, if replacing a compressor in a circuit with a larger one with a higher stand-alone efficiency, the heat pump cycle might experience bottle-necking in the heat exchangers, resulting in frequent start/stop of the compressor. This could lead to the whole system being less efficient, even though the new potential compressor have a higher efficiency than the original.

Refrigerants for heat pump condensing driers

Different types of refrigerants currently exist in tumble driers on the market. These range from F-gasses (Like R134a) to organics (Like R290/Propane). The type of refrigerant is chosen based on the sought temperature levels and specific compressor and its corresponding pressure ratios. No "Best available" refrigerant is thus available, however, organic refrigerants are preferred from a global warming potential perspective, although they may not necessarily be the optimal for increasing the efficiency of the whole heat pump circuit.

Drum, bearings, and sealing for all drier types

The drum itself can be of different kinds of material (e.g. stainless steel, steel, zinc). This have however no impact on energy efficiency, and only on the look and feel of the model.

The sealings are crucial to the condensation efficiency of the drier, but also to the energy consumption of the drum motor. A better seal causes more friction when turning the drum, and thus requires more torque from the drum motor. The energy and condensation efficiency of the drier are thus to some extent inversely proportional. If the drier however is places in a heated room, a low condensation efficiency requires additional ventilation and thus reduces the overall system energy efficiency.

Filters for all drier types

The lint filters act as a protective screen against lint-build up in the machine. Clogged filters reduce the process air flow, which reduces the drying efficiency. This effect is present as soon as the cycle starts, and thus marginally increases energy consumption during the cycle[147]. Designing filters less prone to clogging, or simply with better flow characteristics, reduces this effect and is thus advantageous to the energy efficiency.

Additional features

Network connectivity: Some high-end tumble driers from major manufactures are beginning to be equipped with modules for internet connectivity over LAN or Wi-Fi. This enables control of the unit with a dedicated smartphone application, for remote start operations and for notifications when the cycle is completed.

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[147] "EXPENSIVE MEASURES FOR THE ENVIRONMENT", Berge et al., RÅD & RÖN No. 7, 2012

Self-cleaning heat exchangers for condensing driers: Top model heat pump driers can be equipped with self-cleaning condenser heat exchangers[148], by flushing the heat exchanger during the drying cycle. This removes the need for regularly maintaining the heat exchanger. This is an extra feature, which might reduce efficiency losses through wear and lint build up, which otherwise could lead to significantly higher energy consumption and cycle times[147].

Some manufactures claim that the self-cleaning heat exchanger technology reduces the lifetime of the drier, as the water-and-lint slurry eventually accumulates (if not cleaned every 20 cycles as recommended by some manufacturers), in the unit and leads to clogging in inaccessible parts of the machine which can then only be remedied by a repair.

4.1.2 Best Available Technology BAT

The list of improvement-capable components can be summarized similarly to the average tumble drier in Table 36. Table 37 shows the BAT for each component. Note that the heat pump driers *always* outperform the other types and should hence still be classified as the BAT tumble drier.

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[148] Condenser here being the *water* condenser, and the heat-pump cycle evaporator

Table 37: List of components for the BAT-tumble drier.
HP-C = Condensing heat pump drier, HE-C = Condensing heating element drier, HE-V = air-vented heating element drier, GA-V = air-vented gas fired drier.

Tumble drier technology/Component	BAT-Tumble drier	*Relevant for*			
		HP-C	**HE-C**	**HE-V**	**GA-V**
MOTOR					
Motor type setup (One or multiple)	One / Multiple	x	x	x	x
Motor type (Drum)	BLDC[149]	x	x	x	x
Motor type (Compressor)	BLDC[149]				
↳ If permanent magnet, has RER	No	x	x	x	x
VSD on motor drum drive	Yes	x	x	x	x
VSD on compressor motor	Yes	x			
CONTROLLER					
Type of automatic controller	Automatic moisture sensor controller (direct way)	x	x	x	x
HEAT EXCHANGER (Air to air)					
Heat exchanger material	Aluminium		x		
Heat exchanger type	Plate-fin		x		
Self-cleaning heat exchangers	No		x		
HEAT EXCHANGER (Refrigerant - air)					
Heat exchanger material	Aluminium fins + cobber tubes	x			
Heat exchanger type	Fin-and-tube	x			
Self-cleaning heat exchangers	No / Yes	x			
COMPRESSOR					
Compressor size	400-600 W	x			
DRUM					
Drum material	Stainless Steel	x	x	x	x
Direct Drive	No	x	x	x	x
Drum leakage	Low (<10%)	x	x		
USER INTERFACE					
Eco-mode program	Yes	x	x	x	x
FILTERS[143]					
Anti-clogging design	Yes	x	x	x	x

4.1.3 Best Not Yet Available Technology BNAT

None of the BNAT technologies described in the preparatory study have emerged on the market. These include:

[149] A synchronous permanent magnet motor, i.e. brushless permanent magnet motor (BLDC). Can also be referred to as ECM/PMSM

- Modulating gas driers
- Vacuum driers
- Mechanical steam compression driers
- Microwave driers

They are hence still considered as BNAT technologies in this study. Additionally, a new technology is being tested at the University of Florida, which uses piezoelectric oscillators to mechanically dry the clothes by "vibrating" it at ultrasonic frequencies instead of using heat[150]. This means that the water is physically removed instead of being evaporated, which removes the need to overcome the latent heat of the water in the evaporation phase. This could reduce drying times, as well as reduce the energy consumption by (reported) up to 70%. No news about production timelines is available as of February 2018.

Furthermore, self-cleaning lint filters are under development. This could reduce the need for cleaning the lint filter, and thus lead to energy efficiency improvements for end-users not regularly cleaning the filter, as only 45% of users do this before every cycle (see Figure 34).

4.2 Production and distribution

The production and distribution provide a quick overview of the material composition and distribution of tumble driers. The inputs will be used to model the environmental footprint in later task. The material composition also gives valuable inputs to the discussion on resource efficiency.

4.2.1 Bill-of-Materials (BOM)

This section presents the BOM of tumble driers. The presented values will be used as inputs in the EcoReport Tool for Task 5.

Bill-of-Materials (BOM) of tumble driers

The material composition and weight of tumble driers are based on stakeholder input and are somehow similar to the values presented in the preparatory study, but with the addition of heat pump tumble driers. The material composition is of great importance to the recyclability since some materials are easier to recycle than others which will have an effect in later tasks. No data is available for gas tumble driers, so they are assumed to have a material composition similar to a regular air-vented type.

The assumed material composition of tumble driers is presented in Table 38.

[150] https://energy.gov/sites/prod/files/2016/04/f30/31297_Momen_040516-1205.pdf

Table 38: Assumed average material composition of tumble driers in the preparatory study

Material Type	Materials (examples)	Air-vented – Heat element	Condenser – Heat element	Condenser – heat pump
Bulk Plastics	PP, PP GF, ABS, PA GF	9300	12800	13900
TecPlastics	Elastomere	900	679	1200
Ferrous	Sheet metal steel	18700	23473	18500
Non-ferrous	Aluminium, copper	150	1364	3500
Coating		0	0	0
Electronics	Various	5600	6040	13350
Misc.		2800	2800	6800
Total		**37450**	**45440**	**57650**

It appears that air-vented tumble driers are approximately 10 kg lighter than condenser heat element driers and 20 kg lighter than condenser heat pump driers. Condenser heat pump driers have the highest use of materials and also the highest consumption of electronics. The amount of ferrous are almost identical for these types of tumble driers, but the amount of bulk plastic is considerable higher for the condenser types.

4.2.2 Primary scrap production during manufacturing

The primary scrap production is estimated to be negligible. It is assumed that cuttings and residues are directly reused into new materials. So, the actual losses of materials are low.

4.2.3 Packaging materials

Cardboard, plastic and expanded polystyrene are used to protect the products during transport. More packing materials are sorted by the end-user and recycled. Cardboard are easily recyclable for the next purpose while the plastic likely is burned or recycled otherwise. Regarding the expanded polystyrene it can be compressed and recycled into polystyrene. The problem is the density and volume of the expanded polystyrene. It must be compressed to make it both affordable and environmentally sound.

4.2.4 Volume and weight of the packaged product

The volume of the packaged product is assumed to be same as the standard dimensions of tumble driers including five additional centimetres due to packaging such as polystyrene. This means that the volume of the packaged product (full size tumble drier) is:

$$Volume_{full\ size} 85\ cm\ \times 65\ cm \times 65cm = 0.36\ m^3$$

4.2.5 Means of transport

The means of transport are often negligible in life cycle assessments since the impact often is small compared to the environmental impact of the rest of the product. Most tumble driers are assumed to be shipped by freight ship or by truck. Both means of transport have in general a low impact in the final assessment.

4.3 End-of-Life

Resource efficiency is a growing concern within Europe. More raw materials are categorised as critical and the dependency of these materials are increasing. In addition, it seems that more resource requirements are included in ecodesign Regulations. To improve the resource and material efficiency the following elements are key parameters;

- Recyclability: Identifying materials that hinder recycling with a view to assess possibilities to avoid them in the product design. The recyclability of tumble driers is directly addressed in section 4.3.1.
- Reparability: Identification of spare parts (those which fail too early in driers lifetime) Reparability and ease of disassemble are often interconnected and are discussed in the following sections
- Disassembly: Removal of certain components with a view to assess possibilities for increase their reuse and/or recycling at end of life (i.e. by easy removal) Reparability and ease of disassemble are often interconnected and are discussed in the following sections

4.3.1 Recyclability of tumble driers

After collection, tumble driers are treated at suited facilities. Tumble driers with heat pump technology are handled together with other appliances containing refrigerants such as refrigerators. These appliances are treated at specialised facilities which can handle the refrigerants. The waste process flow[151] for refrigerants appliances (RA) are visualised in Figure 48.

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[151] http://www.sciencedirect.com/science/article/pii/S0921344915300021

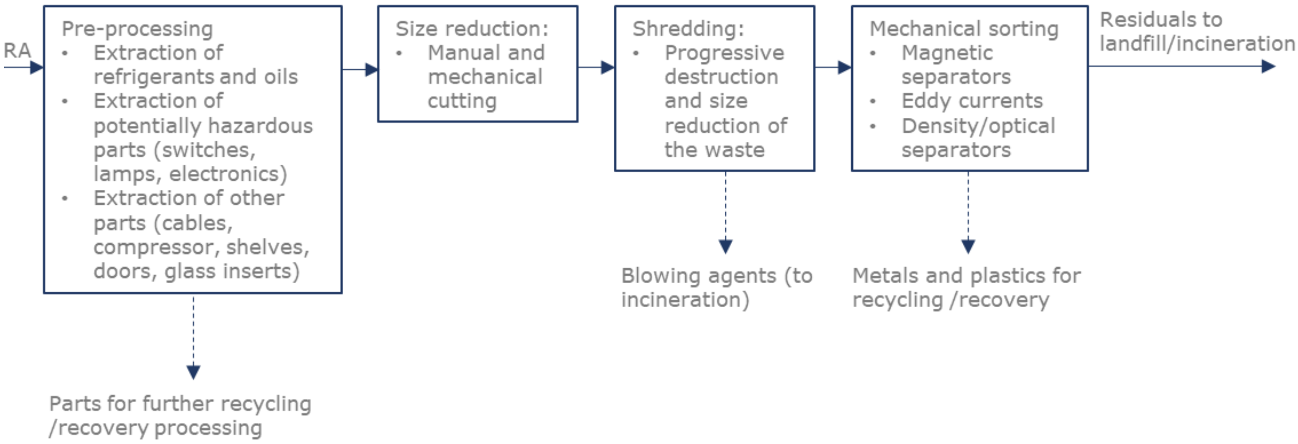

Figure 48: The waste process flow for commercial refrigerants appliances

The pre-processing[152] is the first step in the recycling process of tumble driers containing refrigerants. This first step often consists of manual removing of targeted components and/or materials for further treatment. The pre-processing is very important in connection with an effective recycling process by reducing the risk of contamination, quickly recover selected valuable materials and allow compliance with current legislation on hazardous substances and waste and prevent damage to the facility in the following steps. It is also during the pre-processing the refrigerants and oils are removed by piercing the tubes followed by suction to safely remove these substances. The heat exchangers of tumble driers with heat pumps are likely to be removed since they may contain a lot of copper. According to the WEEE Directive components such as electronic components (e.g. printed circuit board, capacitors, switches, thermostat, liquid crystal displays) and lighting systems (gas discharge lamps) are additionally dismantled when present. Equipment with large dimensions might be cut to smaller pieces before shredding.

Next step[153] is shredding, which reduces the tumble driers in smaller pieces. These facilities also handle insulation foams which may contain different hydrocarbons (if present) so these are removed in an initial shredding in closed atmosphere. These foams are usually burned.

After the equipment has been shredded into smaller pieces (approximately 1 cm to 10 cm) different technologies handle the sorting. These technologies are often:

- Magnetic separation removing ferrous metals
- Eddy current separators removing non-ferrous metals such as copper, aluminium, and zinc
- Density separators for different types of plastic.

[152] http://www.sciencedirect.com/science/article/pii/S0921344915300021
[153] http://www.sciencedirect.com/science/article/pii/S0921344915300021

Air-vented and condenser heat element tumble driers (without heat pump) are assumed to be recycled at regular shredders which are very similar to the above description except the handling of refrigerants. This means that the tumble driers are:

- Pre-processed – extraction of cables and some electronics
- Size reduced – manual and mechanical cutting
- Shredded – Progressive destruction and size reduction
- Mechanical sorted - magnetic separation, eddy current, density separators and optical separators

The effectiveness of the recycling process for all types of tumble driers (the share of recovered, recycled, and reused materials) is based on the EcoReport tool[154] but updated regarding plastics[155]. The recycling rates used in the current study are presented in Table 39.

Table 39: Recycling rates from EcoReport Tool adopted in the current study

	Bulk Plastics TecPlastics*	Ferro Non-ferro Coating	Electronics	Misc.	refrigerant
EoL mass fraction to re-use, in %	1%	1%	1%	1%	1%
EoL mass fraction to (materials) recycling, in %	29%	94%	50%	64%	30%
EoL mass fraction to (heat) recovery, in %	40%	0%	0%	1%	0%
EoL mass fraction to non-recov. incineration, in %	0%	0%	30%	5%	5%
EoL mass fraction to landfill/missing/fugitive, in %	31%	5%	19%	29%	64%
TOTAL	100%	100%	100%	100%	100%

**Adjusted values compared to the EcoReport tool*[156]

With these numbers the total recycling rate (including incineration) is roughly 70% which is in line with information provided by stakeholders. The numbers also express high recycling rates for metals and lower rates for plastic. Traditionally it is also easier for recycling facilities to recover the value of metals than plastic. Plastics are often mixed with other types of plastics which challenge the quality of the recycled plastic. Often recycled plastics are downgraded if not properly separated. Manufacturers of tumble driers have

[154] http://ec.europa.eu/growth/industry/sustainability/ecodesign_da
[155] Plastic Europe, Available at: http://www.plasticseurope.org/documents/document/20161014113313-plastics_the_facts_2016_final_version.pdf
[156] Plastic Europe, Available at: http://www.plasticseurope.org/documents/document/20161014113313-plastics_the_facts_2016_final_version.pdf

expressed concern towards regulatory measures that promote manual disassembly at the end-of-life due to economic barriers for the recyclers.

4.3.2 Design options regarding resource efficiency

Different approaches can be implemented towards improved resource efficiency at End-of-Life. Several options are available for design improvements and covers both more holistic guidelines and product specific suggestion.

Common "design for X" practices which cover all types of EEE products could be[157]:

- Minimise the number and type of fasteners, so fewer tools are needed during disassembly and repair
- The fasteners should be easily accessible and removable
- Easy to locate disassembly points
- If snap fits are used, they should be obviously located and possible to open with standard tools to avoid damaging the product during repair.
- It is beneficial if fasteners and materials are either identical or are compatible with each other in the recycling process
- The use of adhesive should be minimised
- Minimise the length of cables to reduce the risk of copper contamination, or connection points could be designed so they can break off
- Simple product design is preferable

These suggestions are not specifically targeting tumble driers, they are suggestions for all EEE products, which need to be evaluated on a case by case basis. Some of these suggestions are targeting manual disassembly which is not assumed to be the preferred recycling technology within EU. Though, if tumble driers are easy to disassemble more people might consider repairing the product.

Design for recycling mainly focuses on the recycling compatibility of different materials avoiding losses at End-of-Life. This can be done by respecting a few common guidelines such as minimising the use of non-reversible adhesives. Even the suggestions seem simple, design for recycling is quite complicated due to the mix of products at End-of-Life. Different products are discarded together which increases the complexity and risk of contamination. Even within the same product group contaminant can appear. To prevent contamination at End-of-Life and to improve the quality of the recycled material it is important to consider

[157] Chiodo, J., 2005. Design for Disassembly Guidelines. Available at: http://www.activedisassembly.com/strategy/design-for-disassembly/.

the material mix and how the different materials are liberated at End-of-Life. In design for recycling, it is important to consider[158]:

To reduce the use of materials, and especially the use of materials that will cause loss or contamination in the recycling process. It should be considered how the materials would behave in the sorting and processing at End-of-Life

- To identify materials in assemblies combined in an inappropriate way so resources are lost during recycling. E.g. the connection between a metal screws and plastic, where one of them may be lost due to incomplete liberation. Also, some mix of metal are problematic, and the different types om smelters cannot handle all types of metal. In Figure 49 the metal wheel is shown which explains which resources can be recovered by the different smelters. In Table 42 a rough guideline for plastic recyclability is shown.
- Proper labelling both on plastic, but also general futures such as marking of tapping points of generators
- Minimise the use non-reversible adhesives, and avoid the use of bolt/rivets to obtain maximum liberation at End-Of-Life

Other relevant measures for improved resource efficiency are discussed in section 3.2 where availability of spare parts, repair instructions and prolonged lifetime is discussed.

Guidelines based on resource criticality

The awareness of resource criticality is increasing, and the Commission carries out a criticality assessment at EU level on a wide range of non-energy and non-agricultural raw materials. In 2017, the criticality assessment was carried out for 61 candidate materials (58 individual materials and 3 material groups: heavy rare earth elements, light rare earth elements and platinum group metals)

The following main parameters are used to determine the criticality of materials[159]:

- Economic importance - the importance of a material for the EU economy in terms of end-use applications and the value added of corresponding EU manufacturing sector.
- Supply risk - reflects the risk of a disruption in the EU supply of the material. It is based on the concentration of primary supply from raw materials producing countries, considering their governance performance and trade aspects.

[158] Reuter, M.A. & Schaik, A.V.A.N., 2013. 10 Design for Recycling Rules, Product Centric Recycling & Urban / Landfill Mining. , pp.1–15.

[159] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_da

The updated list of critical raw materials is presented in Table 40.

Table 40: List of critical raw materials

Critical raw materials 2017			
Antimony	Fluorspar	LREEs	Phosphorus
Baryte	Gallium	Magnesium	Scandium
Beryllium	Germanium	Natural graphite	Silicon metal
Bismuth	Hafnium	Natural rubber	Tantalum
Borate	Helium	Niobium	Tungsten
Cobalt	HREEs	PGMs	Vanadium
Coking coal	Indium	Phosphate rock	

*HREEs=heavy rare earth elements, LREEs=light rare earth elements, PGMs=platinum group metals

Tumble driers may contain several raw materials categorised as critical. Raw materials like vanadium and phosphorous are in some designations of steel used as alloying elements. These alloying elements are not included in this assessment as they are very difficult to quantify, and more obvious choices are present such as:

- Printed circuit boards which may contain several critical materials such as gold, silver, palladium, antimony, bismuth, tantalum etc.[160]
- Compressor and heat exchangers which may contain copper (but according to manufactures it is possible also to produce heat exchangers with aluminium fins and tubes)
- Wires which may contain copper
- Motors which may contain copper and rare earth elements (magnets)

The composition of printed circuit boards is difficult to quantify but it is estimated as low grade for tumble driers in general. The product development of some tumble driers indicates higher grades of circuit boards in the future due to the implementation of more functions (network functions).

Printed circuit board are already targeted components according to the WEEE Directive and compressors, heat exchanger and wires are already target due to their high amount of copper. Copper is also very important to remove before shredding to minimise the risk of copper contamination in the iron fraction since it directly can influence the mechanical properties of the recycled iron/steel[161]. Avoiding contaminants is one of the key points of design for recycling guidelines. If the heat exchanger consists of aluminium fins and cupper tubes the aluminium is likely to be lost in the recycling process, so it could be beneficial if the heat exchangers are made of the same material.

[160] http://www.wrap.org.uk/sites/files/wrap/Techniques%20for%20recovering%20printed%20circuit%20boards%2C%20final.pdf
[161] http://www.rmz-mg.com/letniki/rmz50/rmz50_0627-0641.pdf

Furthermore, manufactures have indicated that the drum often are made of stainless steel (which may contain rare earths elements as alloying elements) only for the feel and look of the drier. In principle it could be beneficial to use regular steel as long as the lifetime not are affected.

Regulatory measures

Material efficiency requirements can be very difficult to model, as the material efficiency is dependent on the waste handling system which again are dependent on the commodity prices. The current preferred waste processing is shredding but within the next 20 years it may change significantly, and it is therefore difficult in later task to quantify any measure towards improved material efficiency. Also, when products are shredded with other types of products the impact of any requirements toward a specific product may be reduced. Material requirements may therefore have greater effect if they are aligned across all product groups. A summary of the different requirements related to material efficiency in other regulations (adopted and not yet adopted) are presented in Table 41.

Table 41: Alignment with proposals from other Regulations

	Information requirements for refrigeration gases	Requirements for dismantling for the purpose of avoiding pollution, and for material recovery and recycling	Spare part availability	Spare part maximum delivery time	Access to Repair and Maintenance Information
Dishwashers (Suggestion)	x	x	x	x	x
Washing machines (Suggestion)	x	x	x	x	x
Water Heaters					x
Domestic and commercial ovens, hobs and grills					x
Residential Ventilation					x
Circulators and pumps					x
Ventilation Fans					x
Electric motors					x
Vacuum cleaners					x
Local room heating products					x
Domestic and commercial ovens, hobs and grills					x
TVs					x
Personal computers and portable computers		x			

Dishwashers and washing machines may in the future have the most ambitious requirements regarding resource efficiency[162]according to proposed amendments to the current Ecodesign Regulations for these products[163].These Regulations are not yet adopted but it seems to be the general trend. Previously there have been different requirements regarding information relevant for the disassembly but one of the greatest barriers towards increased repair and refurbishment is the lack of available spare parts[164]. By alignment with other Regulation it will be insured that all product groups constitute to transition from a linear economy to a more circular economy.

Recommendations regarding resource efficiency

The low collection rate of tumble driers can challenge the improvement potential of any suggestions regarding resource efficiency since many products do not reach the desired recycling facility. The collection rate is expected to increase and fulfil the WEEE Directive in 2019. The current low collection rates cannot be directly addressed in the Ecodesign Regulation for tumble driers since this is not related to the design of the product.
Based on the list of critical raw materials and the WEEE Directive the following components and materials are of special interest:

- Printed circuit boards which may contain several critical materials such as gold, silver, palladium, antimony, bismuth, tantalum etc.[165]
- Compressor and heat exchangers which may contain copper (but according to manufactures it is possible also to produce heat exchangers with aluminium fins and tubes)
- Wires which may contain copper
- Motors which may contain copper and rare earth elements (magnets)

By alignment with other Regulations (specially with the suggested dishwasher and washing machine Regulation printed circuit boards are easily removed when they are larger than 10 cm^2 which also seems very beneficial from a critical resource perspective and supporting the WEEE Directive (see Annex II). Some requirements may be difficult to address from a market surveillance perspective because the requirements are difficult to control such as requirements of ease of dismantling. Though, these requirements are proposed in

[162] Note that vacuum cleaners also have ambitious requirements with durability and lifetime, which are not reflected in Table 41.
[163] Proposals was discussed at meetings in Consultation Forum on 18 and 19 December 2017. The working document where these suggestions are presented are available on: https://www.eceee.org/ecodesign/
[164] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.
[165] http://www.wrap.org.uk/sites/files/wrap/Techniques%20for%20recovering%20printed%20circuit%20boards%2C%20final.pdf

amendments to the dishwasher and washing machine ecodesign Regulations and the following is stated:

"Accessing components shall be facilitated by documenting the sequence of dismantling operations needed to access the targeted components, including for each of these operations, the type and the number of fastening techniques(s) to be unlocked, and tool(s) required."

I. Annex I

Country	Coverage of GfK data	Population	BNP (bill. EUR)
Austria	90%	8 690 076	349.5
Belgium	88%	11 311 117	421.6
Czech Republic	89%	10 538 275	163.9
Germany	74%	82 175 684	3134.0
Denmark	83%	5 659 715	266.2
Spain	83%	46 445 828	1114.0
Finland	82%	5 487 308	214.1
France	90%	66 759 950	2225.0
Great Britain	95%	65 382 556	2367.0
Greece	95%	10 783 748	175.9
Croatia	75%	4 190 669	45.8
Hungary	94%	9 830 485	112.4
Ireland	90%	4 724 720	265.8
Italy	89%	60 665 551	1672.0
Luxembourg	70%	576 249	54.2
Netherland	81%	1 697 9120	697.2
Poland	93%	37 967 209	424.3
Portugal	94%	10 341 330	184.9
Romania	90%	19 760 314	169.6
Sweden	85%	9 851 017	462.4
Slovenia	85%	2 064 188	39.8
Slovakia	89%	5 426 252	81.0
Bulgaria	0%	7 153 784	47.4
Cyprus	0%	848 319	17.9
Latvia	85%	1 968 957	25.0
Lithuania	85%	2 888 558	38.6
Estonia	85%	1 315 944	20.9
Malta	0%	434 403	9.9
Total		**510 221 326**	**14800**
Total coverage	**85%**	**430 709 693**	**12580**

II. Annex II

Guidelines supporting the WEEE Directive

The WEEE Directive contains several parts supporting resource efficiency and selective requirements. How the Directive is interpreted and adopted to the member states can vary greatly. Based on WEEE-Directive special articles and annexes are highlighted below to pinpoint which design improvements which could comply with the Directive:

- Article 4, Product design: *"Member States shall, without prejudice to the requirements of Union legislation on the proper functioning of the internal market and on product design, including Directive 2009/125/EC, encourage cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials."*
- Article 8, Proper treatment:
    - Member States shall ensure that all separately collected WEEE undergoes proper treatment including the removal of the following components following substances, mixtures and components:
        - Mercury containing components, such as switches or backlighting lamps
        - Batteries
        - Printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres,
        - Plastic containing brominated flame retardants,
        - Chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC),
        - External electric cables,
    - The following components of WEEE that is separately collected have to be treated as indicated:
        - Equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits: the gases must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation
- Article 15 Information for treatment facilities: *"In order to facilitate the preparation for re-use and the correct and environmentally sound treatment of WEEE, including maintenance, upgrade, refurbishment and recycling, Member States shall take the necessary measures to ensure that producers provide information free of charge*

about preparation for re-use and treatment in respect of each type of new EEE placed for the first time on the Union market within one year after the equipment is placed on the market."

Design for re-use, dismantling and recovery of WEEE all fits in the category of design for repair described in Task 3. The overall purpose of design for repair is to ease the repair process by allowing easy access to critical components. These parts should ideally be easily located and changed if possible. If printed circuit boards are located and removed easily it also fits with the proper treatment definition if this information also are available for the recycling facilities.

III. Annex III

In Figure 49 the metal wheel is shown which explains which resources can be recovered by the different smelters. In Table 42 a rough guideline for plastic recyclability is shown.

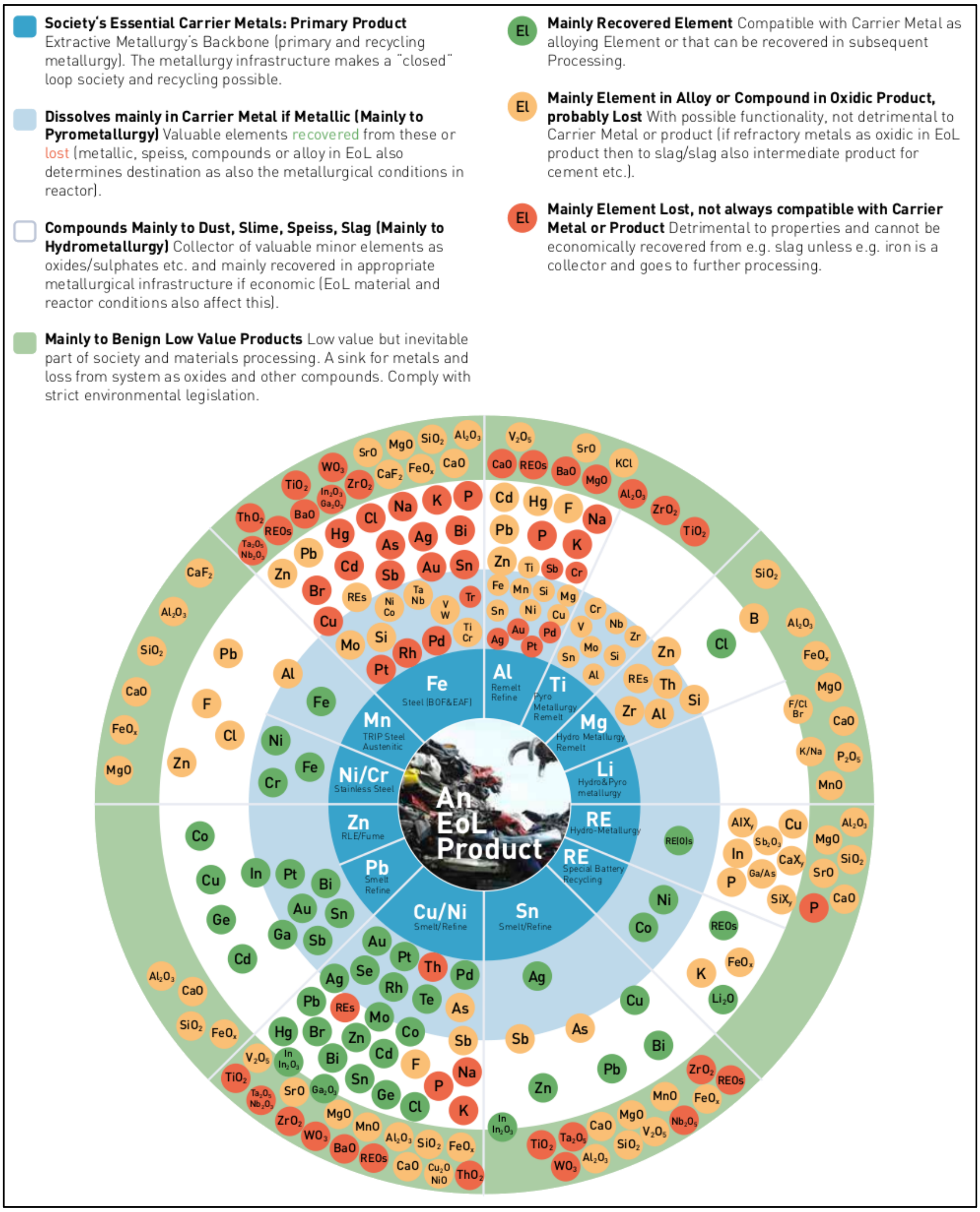

Figure 49: Metal wheel. The metal wheel shows which resources that can be recovered at the different types of smelters[166]

[166] http://wedocs.unep.org/handle/20.500.11822/8423

Table 42: Recycling compatibility of different types of plastic. 1= Compatible, 2 = Compatible with limitations, 3 = Compatible only in small amounts, 4 = Not compatible[167]

Important Plastics	PE	PVC	PS	PC	PP	PA	POM	SAN	ABS	PBTP	PETP	PMMA
PE	1	4	4	4	1	4	4	4	4	4	4	4
PVC	4	1	4	4	4	4	4	1	2	4	4	1
PS	4	4	1	4	4	4	4	4	4	4	4	4
PC	4	3	4	1	4	4	4	1	1	1	1	1
PP	3	4	4	4	1	4	4	4	4	4	4	4
PA	4	4	3	4	4	1	4	4	4	3	3	4
POM	4	4	4	4	4	4	1	4	4	3	4	4
SAN	4	1	4	1	4	4	4	1	1	4	4	1
ABS	4	2	4	1	4	4	3	4	1	3	3	1
PBTP	4	4	4	1	4	3	4	4	3	1	4	4
PETP	4	4	3	1	4	3	4	4	3	4	1	4
PMMA	4	1	3	1	4	4	3	1	1	4	4	1

[167] Chiodo, J., 2005. Design for Disassembly Guidelines . Available at: http://www.activedisassembly.com/strategy/design-for-disassembly/.