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COMMISSION STAFF WORKING DOCUMENT

IMPACT ASSESSMENT

Accompanying the document

COMMISSION REGULATION (EU) .../...laying down ecodesign requirements for electronic displays pursuant to Directive 2009/125/EC of the European Parliament and of the Council,
amending Commission Regulation (EC) No 1275/2008,
and repealing Commission Regulation (EC) 642/2009

and

COMMISSION DELEGATED REGULATION (EU) …/... supplementing Regulation (EU) 2017/1369 of the European Parliament and of the Council with regard to energy labelling of electronic displays

and repealing Commission Delegated Regulation (EU) No 1062/2010

{C(2019) 1796 final} - {C(2019) 2122 final} - {SEC(2019) 339 final} -
{SWD(2019) 355 final}

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ANNEXES

Annex 10: IAB opinion of 4 September 2013 & adjustments made

The Impact Assessment Board (IAB) gave its positive opinion on the first IA report in the meeting of 4 September 2013, but stated that the report should be improved in a number of respects.

First, it should better explain why new and more extensive regulation would be needed given the limited role of ecodesign and energy labelling measures in energy savings in the past. Second, it should clarify how the proposed options would address these issues and strengthen the assessments of their impacts, particularly with regard to compliance costs and the relevance of labelling information for products for which new features are likely to be an important buying factor. Finally, the report should more systematically address the need for, and the impact of, the proposed measures for material resource efficiency. As regards the presentation, the report should be clearer, more focussed and less technical. Acronyms and specific terms should be explained and the report should add links to, or summaries of, the main background studies.

The first issue has been addressed in paragraph 2, where the section on problem drivers and regulatory/market failures was expanded. Amongst others it shows more explicitly how the functional convergence of the various types of electronic displays (televisions, computer monitor, digital photo frames) is a potential threat to the effectiveness of existing measures. It also demonstrates that the industry, despite an impressive track record in reacting to legislation, does not pro-actively address the environmental consequences of new features in display design when not mentioned in legislation.

The second issue brought forward by the IAB is now addressed in Chapter 4, showing how the proposed options address the problem of functional convergence through expansion of the scope as well as illustrating the effective and responsible manner in which requirements on new features (3D, bigger screens, higher resolution, network connectivity, etc.) are phased in. The latest status in pricing, performance and efficiency of the latest UHD TVs has been addressed. Chapter 5 better explains how the proposed option makes compliance testing different, but not necessarily overall more costly. In this context it is relevant, amongst others, that the new dynamic test standard in the proposed option is expected to become the new test standard for electronic displays around the world. The baseline scenario does take the effects of global developments in testing and minimum requirements into account.

The need for material resource efficiency measures, i.e. optimisation for better recycling mainly through requirements dismantlability of certain components mentioned in WEEE and on flame retardants is addressed extensively in the report. At the same time it is also demonstrated that with the new display technologies a large number of ‘old’ environmental issues were solved or significantly reduced and do not require action. Concerns of stakeholders on e.g. enforceability of non-energy related requirements have been taken into account and in the current report it is explained more clearly how and why the initial list of possible requirements was amended in this context.

As regards the level of technical detail, the main IA report now only presents technical knowledge that is indispensable for the understanding. Relevant background information has

been moved to Annexes. For other issues, the report refers more often to an extensive list of literature references to explain technical details. To improve understanding of the technical terms in the text of the IA report, a glossary was added and an overview of acronyms.
Before the 2013 Impact Assessment Board meeting, the impact assessment report was subject to the consultations of the Ecodesign Inter-service Impact Assessment Group. No comments on the substance of the report were provided. None of the members of the Group accepted an invitation to a meeting to discuss the impact assessment report.

Further background on why new and more extensive regulation would be needed given the limited role of ecodesign and energy labelling measures in energy savings in the past is given below.

Annex 11: Administrative burden

In the impact assessment for the new Energy Label Regulation (SWD(2015)/139 of 15.7.2015) the administrative burden of the measures under the new Energy Label Regulation are indicated. Hereafter the findings are applied to the group of electronic displays.

Administrative costs are defined as "the costs incurred by enterprises, the voluntary sector, public authorities and citizens in meeting legal obligations to provide information on their action or production, either to public authorities or to private parties"[1] The Commission's in-house Administrative Burden Calculator was used in the impact assessment to calculate administrative cost for businesses and public authorities for measures 1 and 3.

Label transition for the A-G label (Measure 2)

Suppliers will have to supply two labels instead of one for a period of 6 months at a cost of € 0.3 to print a label[2]. For ~16-17 million electronic displays sold in 6 months, this means a total of approximately € 5 million for suppliers to temporarily provide a second label for a transition of one label to another. Furthermore, suppliers may have to supply some replacements labels on request of dealers depending on the delivery channel for replacement labels.

Dealers have to re-label around 2.5% of products on stock/display or on the internet. An average time of five minutes per product is assumed at a tariff of €14.30/h, resulting in €1.20 per label and –for 0.82 million electronic displays—a total of €1 million.

Mandatory product registration database (Framework Labelling Regulation 2017/1369)

The key burdens generated by this option are expected to be similar to those for the product registration database for radio equipment[3]:

– Training staff to become acquainted with the system: this is a one-time investment and not considered significant.
– Depending on the design for the operation of the database, upload manufacturer information and obtain manufacturer code. This is again considered not significant.
– Upload product specific information: this implies selecting appropriate information, formatting, and actually uploading the information. This is considered to be significant.

For electronic displays an average figure of 1000 models[4] per year is deemed an appropriate estimate[5]. Two hours of collection and registration time per model family is assumed[6], which

[1] Commission impact assessment Guidelines

[2] Estimated at 0.50 Australian dollar (exchange rate at the time approximately 0.6 €/Australian dollar) by George Wilkenfeld and Associates Pty Ltd, Regulatory Impact Statement, Energy Labelling and Minimum Energy Performance Standards for Household Electrical Appliances in Australia, February 1999, p. 40

[3] SWD(2012) 329 final, p.31

[4] Equivalent models (i.e. models that are exactly the same with regard to energy efficiency, but sold under different model codes or even brand names) can be registered through a single registration and therefore count here as one model.

[5] For electronic products 2500-3000 per product group based on Energy Star registrations, for many domestic appliances such as washing machines, dishwashers, tumble driers vacuum cleaners it is likely to be much lower, possibly as low as 500. Industry databases for other domestic appliances such refrigeration and cooking points to about 2000-3000. For heating/cooling equipment it is estimated to be lower, in the range of 250-1000 depending on the specific product group. For commercial and industrial products it would be in the range of 2000-3000 for motors and fans, but as low as 50 for power transformers (VHK)

[6] At an employee tariff of € 32.10 per hour representative for professionals

corresponds with the estimated administrative costs borne by suppliers for Australia's product registration database, i.e. €60/model [7]. For the 1000 models this results in €60’000 per year.

The burden for Member States' market surveillance authorities to obtain documents is significantly reduced by this measure. It is, however, assumed that they spend the freed-up time on other market surveillance activities instead thereby contributing to higher compliance rates.

The costs for the Commission to set up the database are likely to be similar to the product registration base for radio equipment, adjusted for the number of models to be registered and kept in the database. The cost for the product registration base for radio equipment was estimated at € 300.000 investment and € 30.000 annual maintenance costs for registration of 5000 models per year[8]. Based on the above estimate of 1000 models per year, the share of electronic displays in the total Commission investment is € 60’000 and the maintenance costs are estimated at € 6’000 per year.

Expand the database study, Commission costs

The budget for the current three-year study covering six products was € 500.000[9]. The cost for the Commission to cover about 30 products would thus be approximately € 1 million per year. For electronic displays (1 of 30 product groups) it would amount to € 33 000/year.

Change 'least life cycle cost' requirement

This measure does not require administrative effort additional to business-as-usual. However, there are likely to be compliance costs for business in order to meet the more stringent requirements. Such compliance costs are likely to be negligible for product groups that have energy labels, where almost all businesses would, because of the energy label, in any case already go beyond the minimum ecodesign requirements. For product groups only covered by ecodesign requirements (and no energy labels) the compliance cost in terms of redesign may be significant for some businesses. A recent case study for laptops estimated that the total design costs for compliance with the seven applicable EU internal market directives and regulations, including ecodesign, is € 8 million per year[10]. Assuming that: 1) one quarter of that cost is due to ecodesign[11] ; 2) changing the least life-cycle cost requirement to break-even point may increase the design cost by half; and 3) laptops constitute about one third of the ecodesign regulation for computers, the total additional compliance cost above business-as-usual for the 15 regulations for product groups which have no energy label could be € 45 million per year[12].

Support joint surveillance actions Horizon2020

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7 100 Australian dollar per model (exchange rate at the time approximately 0.6 €/Australian dollar). In addition, Australia charges a registration fee of 150 Australian dollar per model (George Wilkenfeld and Associates Pty Ltd, Regulatory Impact Statement Energy Labelling and Minimum Energy Performance Standards for Household Electrical Appliances in Australia: Supplementary Cost-Benefit Analysis on Transition to a Revised Energy Label, November 1999, p. 18)

8 SWD(2012) 329 final, Annex X

9 http://ec.europa.eu/energy/intelligent/files/tender/doc/2013/tender_specifications_eaci_iee_2013_002.pdf

10 SWD(2014) 23 final part 2, p. 52 and 54

11 Although there were seven applicable EU internal market directives that caused the total cost, not all of those impacted design significantly and thus the weight of ecodesign among the seven is estimated to be higher than one seventh: at one fourth.

12 € 8 million divided by 4 (estimated share of impact of ecodesign in EU internal market directives applicable to laptops) multiplied by 0.5 (50% extra design costs on top of business-as-usual due to the change of least life cycle cost requirement to break-even point requirement) multiplied by 45 (to account for all 15 product groups, because laptops only constitute 1/3 of a product group).

Joint surveillance actions fit the requirements and description of 2014 Horizon2020 call on the energy efficiency market uptake segment of "Ensuring effective implementation of EU product efficiency legislation" for which the indicative cost was 1.5-2 million euro for the EU budget[13]. Such a call would be opened every year with the aim to support several joint actions per year. The share of electronic displays (1 of 30 product groups) is estimated at € 60'000/year.

External laboratory testing

Manufacturers of electronic displays use self-declaration to declare relevant values for Ecodesign and Energy Label measures. All manufacturers have facilities for in-house testing, used not just for declaration of Ecodesign and Energy Label values but also for broader Research and Development (R&D) in general.

Market surveillance costs

No precise figures on total Member States expenditure on market surveillance are available, since only about half of the Member States share information of available budgets. In 2011 this was estimated at € 7-10 million[14]. Based on (incomplete) data collected from Member States it is currently likely to be around € 10 million. Electronic displays are one of thirty products for surveillance. Assuming the effort to be equally distributed per product group this amounts to €330'000 of market surveillance costs for surveillance of electronic displays.

Introducing reviewed legislation

Both Ecodesign and Energy Label regulations for televisions already exist, so the infractructure of notified bodies and market surveillance authorities of televisions is already in place in Member States and is assumed to be adequate also for omputer monitors. Furthermore, the legal format is a 'regulation' and thus no transposition in national law is required. As a placeholder it is assumed that in total for all 28 Member States an amount of € 100 000 is required for training and answering questions on the changes in the regulations.

Legal uncertainty: the German judgment

In February 2014 the German court judged that - irrespective of given non-standardized signal paths like DVI or SDI, monitors with HDMI fall under 1062/2010 EU Energy Labelling Regulation (and, due to same definition, logically also under Regulation 642/2009).

Figure 11.1 shows a description of contested facts, with the image of the advertisement (LED monitor showing content considered TV images, but marketed as computer monitor and not a TV monitor). As result, some manufacturers include the energy label in the display box of products marketed as "computer monitors", although these products are, in principle, out of scope of the regulations 642/2009 and 1062/2010.

On the appeal of the plaintiff, the judgment of the 31st Civil Division of the district court of Cologne - 31 O 111/123 - announced on 19.09.2013 is amended:
The defendant is being judged

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13 http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/2362-ee-15-2014.html

14 P. Waide *et al.*, Enforcement of energy efficiency regulations for energy consuming equipment: findings from a new European study, Proceedings of the 6th International Conference EEDAL'11 Energy Efficiency in Domestic Appliances and Lighting

1. in the event of the avoidance of a fine imposed by the court for each case of infringement, up to a maximum of € 250,000, as a substitute for statutory order, or of orderly imprisonment, to its managing directors, for a period of six months, to stop, advertise monitors as shown below without indicating the energy efficiency class for these devices
2. to the claimant € 196.35 plus interest at the rate of five percentage points above the respective base interest rate since 12.04. 2013 to pay.

Oberlandesgericht Köln, 6 U 189/13

Datum:	26.02.2014
Gericht:	Oberlandesgericht Köln
Spruchkörper:	6. Zivilsenat
Entscheidungsart:	Urteil
Aktenzeichen:	6 U 189/13
ECLI:	ECLI:DE:OLGK:2014:0226.6U189.13.00
Vorinstanz:	Landgericht Köln, 31 O 111/13
Normen:	UWG §§ 3 Abs. 2, 4 Nr. 11, 5a Abs. 2 und 4,; EnVKV § 6a;; Del. VO (EU) Nr. 1062/2010

Tenor: Auf die Berufung des Klägers wird das am 19.09.2013 verkündete Urteil der 31. Zivilkammer des Landgerichts Köln – 31 O 111/123 – abgeändert:

Die Beklagte wird veurteilt,

1. es bei Meidung eines vom Gericht für jeden Fall der Zuwiderhandlung festzusetzenden Ordnungsgeldes bis zu 250.000 €, ersatzweise Ordnungshaft, oder von Ordnungshaft, zu vollziehen an ihren Geschäftsführern, bis zur Dauer von sechs Monaten,

zu unterlassen,

wie nachstehend wiedergegeben für Monitore zu werben, ohne die Energieeffizienzklasse für diese Geräte anzugeben:

Figure 11.1: A page from the on-line database of the German Minister of Justice (Source: http://www.justiz.nrw.de/nrwe/olgs/koeln/j2014/6_U_189_13_Urteil_20140226.html)

Annex 12: Consumer understanding of the energy label (displays)

Regulation (EU) 2017/1369 states that when preparing delegated acts, the Commission shall test the design and content of the labels for specific product groups with representative groups of Union customers to ensure their clear understanding of the labels. **A study was so performed in 2017 to inform the design of a new energy label for electronic displays that provides information that consumers find useful in their purchase choice.**

An online survey was conducted with approximately 600 potential consumers in each of 7 countries (4081 respondents in total): Germany, Italy, the Netherlands, Poland, Portugal, Romania, and Sweden (Figure 12.1).

Figure 12.1: Countries in which the user survey was performed.

Respondents were asked how important they considered a number of possible features when buying an electronic display. The features proposed and relevance results are presented in Figure 12.2 (the features proposed include also information not suitable of the Energy label but possibly indicated in a retailers label of a tipical brick&mortar shop).

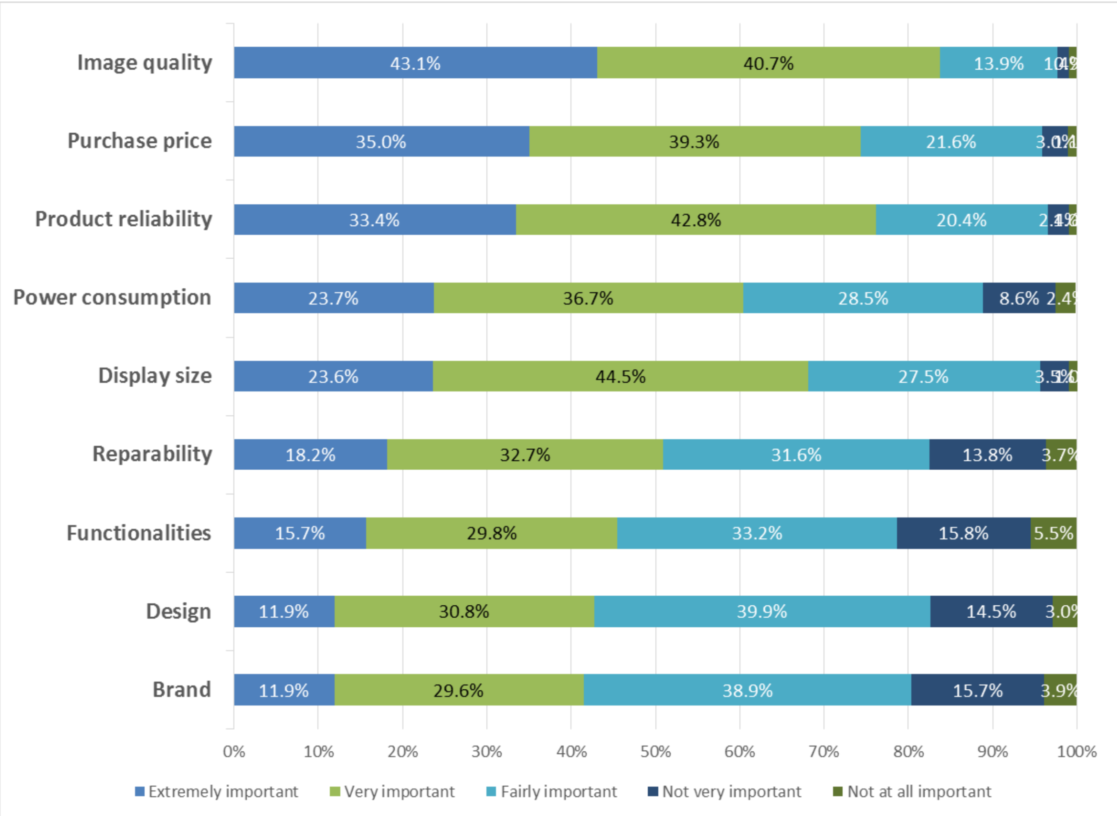


Figure 12.2: Features that consumers find most important when buying a TV or computer display (sample of 4081 respondents).

Some features that were considered relevant are in reality not applicable to a general label (e.g. presence of Internet interface is not applicable to non-smart products such as most of the computer monitors) or are not relevant to differentiate products (e.g. in off-mode or in standby mode, different models may differ for tenths of Watt). Features such as resolution, size, aspect ratio are considered relevant to compare products and use of a standardised external power supply is considered relevant by other one third of respondents but less than energy use information. No relevant difference in understanding emerged from displaying energy use in HDR mode and in the traditional (double scale) one in respect to just one scale.

About half or respondents did not understand the difference between energy efficiency and power consumption information: they inaccurately believed that the same display was more energy efficient and consumed less energy relative to another, whilst this is only the case when comparing two displays with the same display area. 3 different graphical variants of the same indicator were tested, but, as mentioned, some features would be not included to avoid an overcrowding of the label, detrimental for the understanding of the crucial aspects.

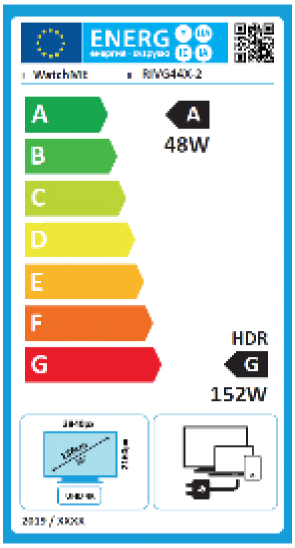


Figure 12.3: Content of the proposed energy label as resulting from the consumer-understanding and connect relevance study (source Centerdata).

Figure 12.3 shows the label content proposed as result of the survey. The graphical layout, however, has to be harmonised with all other products being rescaled as from 2020 and for which an analogous survey was done later.

Annex 13: Background: Energy databases and testing

UHD-OLED

Diagonal Screen Size D	Screen Area A	HDR	Typical On-Mode Power P	Off mode Power	Standby Power	Networked standby	ABC/room-presence
inch	dm²		W	W	W	W	
77	163.4	yes	215	n/a	0.3	0.8	
77	163.4	yes	285	n/a	0.3	0.8	
77	163.4	yes	262	n/a	0.5	3	abc.
77	163.4	yes	220	0	0.42		abc.
77	163.4	yes	245	0.3	0.5		
65	116.5	yes	154	n/a	0.3	0.8	
65	116.5	yes	154	n/a	0.3	0.8	
65	116.5	yes	173	n/a	0.3	0.8	
65	116.5	yes	154	n/a	0.3	0.8	
65	116.5	yes	154	n/a	0.3	0.8	
65	116.5	yes	145	n/a	0.5	0.8	
65	116.5	yes	145	n/a	0.5	0.8	
65	116.5	yes	145	n/a	0.3	0.8	
65	116.5	yes	145	n/a	0.5	0.8	

Diagonal Screen Size D	Screen Area A	HDR	Typical On-Mode Power P	Off mode Power	Standby Power	Networked standby	ABC/room-presence
inch	dm²		W	W	W	W	
65	116.5	yes	154	n/a	0.5	3	abc.
65	116.5	yes	180	0	0.49		abc.
65	116.5	yes	180	0	0.49		abc.
65	116.5	yes	180	0	0.49		abc.
65	116.5	yes	180	0.3	0.5		
65	116.5	yes	180	0.3	0.5		
65	116.5	yes	214	0.3	0.3		
65	116.5	yes	154		0.5		
65	116.5	yes	174		0.12		abc.
65	116.5	yes	152				
65	116.5		155		0.5		
55	83.4	yes	112	n/a	0.3	0.8	
55	83.4	yes	112	n/a	0.3	0.8	
55	83.4	yes	112	n/a	0.3	0.8	

Diagonal Screen Size D	Screen Area A	HDR	Typical On-Mode Power P	Off mode Power	Standby Power	Networked standby	ABC/room-presence
inch	dm²		W	W	W	W	
55	83.4	yes	145	n/a	0.5	0.8	
55	83.4	yes	145	n/a	0.5	0.8	
55	83.4	yes	145	n/a	0.5	0.8	
55	83.4	yes	135	n/a	0.5	3	abc
55	83.4	yes	156	n/a	0.3	n/a	abc
55	83.4	yes	150	n/a	0.3	n/a	abc
55	83.4	yes	150	0	0.5		abc
55	83.4	yes	150	0	0.5		abc
55	83.4	yes	150	0	0.5		abc
55	83.4	yes	148	0	0.5		abc
55	83.4	yes	148	0	0.5		abc
55	83.4	yes	142	0.3	0.5		
55	83.4	yes	178		0.1		abc
55	83.4	yes	111				

UHD-QDOT

Diagonal Screen Size D	Screen Area A	HDR	Typical On-Mode Power P	Off mode Power	Standby Power	Networked standby	ABC/room-presence
88	213.5	yes	395	n/a	0.5	n/a	no
86	203.9	yes	247	n/a	0.3	0.8	
75	155.1	yes	202	n/a	0.3	0.8	
75	155.1	yes	203	n/a	0.5	n/a	no
75	155.1	yes	203	n/a	0.5	n/a	no
65	116.5	yes	149	n/a	0.3	0.8	
65	116.5	yes	140	n/a	0.3	0.8	
65	116.5	yes	102	n/a	0.3	0.8	
65	116.5	yes	102	n/a	0.3	0.8	
65	116.5	yes	215	n/a	0.5	n/a	no

Diagonal Screen Size D	Screen Area A	HDR	Typical On-Mode Power P	Off mode Power	Standby Power	Networked standby	ABC/room-presence
65	116.5	yes	153	n/a	0.5	n/a	no
65	116.5	yes	153	n/a	0.5	n/a	no
65	116.5	yes	153	n/a	0.5	n/a	no
65	116.5	yes	153	n/a	0.5	n/a	no
65	116.5	yes	202	n/a	0.3	n/a	abc.
60	99.2	yes	126	n/a	0.3	0.8	
60	99.2	yes	99	n/a	0.3	0.8	
55	83.4	yes	86	n/a	0.3	0.8	
55	83.4	yes	107	n/a	0.3	0.8	
55	83.4	yes	78	n/a	0.3	0.8	
55	83.4	yes	78	n/a	0.3	0.8	

Diagonal Screen Size D	Screen Area A	HDR	Typical On-Mode Power P	Off mode Power	Standby Power	Networked standby	ABC/room-presence
55	83.4	yes	140	n/a	0.5	n/a	no
55	83.4	yes	140	n/a	0.5	n/a	no
55	83.4	yes	140	n/a	0.5	n/a	no
55	83.4	yes	140	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	149	n/a	0.3	n/a	abc
49	66.2	yes	66	n/a	0.3	0.8	
49	66.2	yes	66	n/a	0.3	0.8	
49	66.2	yes	124	n/a	0.5	n/a	no
49	66.2	yes	124	n/a	0.5	n/a	no

UHD-LED-HDR

Diagonal Screen Size D	Screen Area A	HDR	Typical On-Mode Power P	Off mode Power	Standby Power	Networked standby	ABC/room-presence
##	275.7	yes	413	n/a	0.5	3	abc.
86	203.9	yes	375	n/a	0.5		abc.
85	199.2	yes	168	n/a	0.5	3	abc.
85	199.2		311		0.2		
82	185.4	yes	205	n/a	0.5	n/a	no
75	155.1	yes	132	n/a	0.3	0.8	
75	155.1	yes	205	n/a	0.5	n/a	no
75	155.1	yes	205	n/a	0.5	n/a	no
75	155.1	yes	200	n/a	0.5	n/a	no
75	155.1	yes	200	n/a	0.5	n/a	no
75	155.1	yes	262	n/a	0.5		
75	155.1	yes	259	n/a	0.5	3	abc.
75	155.1	yes	298	n/a	0.5	3	abc.

Diagonal Screen Size D	Screen Area A	HDR	Typical On-Mode Power P	Off mode Power	Standby Power	Networked standby	ABC/room-presence
75	155.1	yes	182	n/a	0.5	3	abc.
75	155.1	yes	130	n/a	0.5	3	abc.
75	155.1	yes	202	n/a	0.5	3	abc.
75	155.1	yes	147	n/a	0.5	3	abc.
75	155.1	yes	153	n/a	0.3	n/a	abc.
75	155.1	yes	205	n/a	0.5		abc.
75	155.1	yes	138	0.3	0.5	1	
75	155.1	yes	160		0.5		
75	155.1		276		0.2		
70	135.1	yes	130	n/a	0.3	0.8	
70	135.1	yes	240		0.5		
65	116.5	yes	104	n/a	0.3	0.8	
65	116.5	yes	104	n/a	0.3	0.8	

Diagonal Screen Size D	Screen Area A	HDR	Typical On-Mode Power P	Off mode Power	Standby Power	Networked standby	ABC/room-presence
65	116.5	yes	104	n/a	0.3	0.8	
65	116.5	yes	104	n/a	0.3	0.8	
65	116.5	yes	136	n/a	0.3	0.8	
65	116.5	yes	136	n/a	0.3	0.8	
65	116.5	yes	118	n/a	0.5	n/a	abc
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no

D	A	hdr	on	off	sb	nw	abc
inch	dm²		W	W	W	W	
65	116.5	yes	154	n/a	0.5	n/a	no
65	116.5	yes	154	n/a	0.5	n/a	no
65	116.5	yes	154	n/a	0.5	n/a	no
65	116.5	yes	154	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	118	n/a	0.5	n/a	no
65	116.5	yes	130	n/a	0.5		
65	116.5	yes	200		0.5		
65	116.5	yes	110		0.5		
65	116.5	yes	210	n/a	0.5	3	abc
65	116.5	yes	164	n/a	0.5	3	abc
65	116.5	yes	129	n/a	0.5	3	abc
65	116.5	yes	114	n/a	0.5	3	abc
65	116.5	yes	114	n/a	0.5	3	abc
65	116.5	yes	114	n/a	0.5	3	abc
65	116.5	yes	114	n/a	0.5	3	abc
65	116.5	yes	114	n/a	0.5	3	abc
65	116.5	yes	110	n/a	0.5	2	no
65	116.5	yes	110	n/a	0.5	2	no
65	116.5	yes	110	n/a	0.5	2	no
65	116.5	yes	167	n/a	0.5	3	abc
65	116.5	yes	119	n/a	0.5	3	abc
65	116.5	yes	119	n/a	0.5	3	abc
65	116.5	yes	119	n/a	0.5	3	abc
65	116.5	yes	123	n/a	0.5	3	abc
65	116.5	yes	124	n/a	0.3	n/a	abc
65	116.5	yes	180	n/a	0.3	n/a	abc
65	116.5	yes	106	n/a	0.3	n/a	abc
65	116.5	yes	109	n/a	0.3	n/a	abc
65	116.5	yes	118	n/a	0.5		abc
65	116.5	yes	99	0.3	0.5	1	
65	116.5	yes	130	0.3	0.5	1.2	
65	116.5	yes	226	0.3	0.5	0.9	
65	116.5	yes	159	0.3	0.5	1.2	
65	116.5	yes	159	0.3	0.5	1.2	
65	116.5	yes	161	0.25	0.5	0.7	
65	116.5	yes	140	0.25	0.5	0.7	abc
65	116.5	yes	120		0.29		
65	116.5	no	185		0.5		
65	116.5	no	118	n/a	0.5		abc
65	116.5	no	165	0	0.38		abc
65	116.5	no	118		0.5		
65	116.5	no	118		0.5		
65	116.5	no	150		0.29		
65	116.5	no	150		0.29		
65	116.5	no	150		0.3		
65	116.5	no	150		0.3		
65	116.5		213		0.5		
65	116.5		147	0.3	0.5	1.2	abc
65	116.5		139	0.3	0.5	1.2	abc
65	116.5		180		0.5		
64	112.9	yes	125	n/a	0.5	*	abc
60	99.2	yes	96	n/a	0.3	0.8	
60	99.2	yes	92	n/a	0.3	0.8	
60	99.2	yes	117	n/a	0.3	0.8	
60	99.2	yes	117	n/a	0.3	0.8	
60	99.2	yes	100	n/a	0.5		
60	99.2		158	0.3	0.5	1.2	abc
60	99.2		158	0.3	0.5	1.2	abc
58	92.7	yes	124	n/a	0.5	n/a	no
58	92.7	yes	99	0.3	0.5	1	
58	92.7	yes	106	0.3	0.5	1	
58	92.7	yes	183	0.3	0.5	0.9	
58	92.7	yes	113	0.3	0.5	1.2	
58	92.7	yes	113	0.3	0.5	1.2	
58	92.7	yes	113	0.3	0.5	1.2	
58	92.7	yes	109	0.3	0.5	1.2	
58	92.7	yes	109	0.3	0.5	1.2	
55	83.4	yes	75	n/a	0.3	0.8	
55	83.4	yes	85	n/a	0.3	0.8	
55	83.4	yes	74	n/a	0.3	0.8	
55	83.4	yes	85	n/a	0.3	0.8	
55	83.4	yes	85	n/a	0.3	0.8	
55	83.4	yes	107	n/a	0.3	0.8	
55	83.4	yes	107	n/a	0.3	0.8	
55	83.4	yes	107	n/a	0.3	0.8	
55	83.4	yes	103	n/a	0.5	n/a	abc
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	111	n/a	0.5	n/a	no
55	83.4	yes	115	n/a	0.5		
55	83.4	yes	150		0.5		
55	83.4	yes	150		0.5		
55	83.4	yes	170		0.5		
55	83.4	yes	137	n/a	0.5	3	abc
55	83.4	yes	109	n/a	0.5	3	abc
55	83.4	yes	100	n/a	0.5	3	abc
55	83.4	yes	100	n/a	0.5	3	abc
55	83.4	yes	100	n/a	0.5	3	abc
55	83.4	yes	100	n/a	0.5	3	abc
55	83.4	yes	100	n/a	0.5	3	abc
55	83.4	yes	106	n/a	0.5	3	abc
55	83.4	yes	85	n/a	0.5	2	no
55	83.4	yes	85	n/a	0.5	2	no
55	83.4	yes	85	n/a	0.5	2	no
55	83.4	yes	85	n/a	0.5	2	no
55	83.4	yes	85	n/a	0.5	2	no
55	83.4	yes	85	n/a	0.5	2	no
55	83.4	yes	134	n/a	0.5	3	abc
55	83.4	yes	103	n/a	0.5	3	abc
55	83.4	yes	103	n/a	0.5	3	abc
55	83.4	yes	103	n/a	0.5	3	abc
55	83.4	yes	103	n/a	0.5	3	abc
55	83.4	yes	112	n/a	0.5	3	abc
55	83.4	yes	93	n/a	0.5	3	abc
55	83.4	yes	112	n/a	0.5	*	abc
55	83.4	yes	96	n/a	0.3	n/a	abc
55	83.4	yes	105	n/a	0.3	n/a	abc
55	83.4	yes	105	n/a	0.3	n/a	abc
55	83.4	yes	102	n/a	0.3	n/a	abc
55	83.4	yes	63	n/a	0.3	n/a	no
55	83.4	yes	86	n/a	0.5		abc
55	83.4	yes	107	0.3	0.5	1.2	
55	83.4	yes	112	0.3	0.5	0.7	abc
55	83.4	yes	137	0.3	0.5	0.7	abc
55	83.4	yes	87		0.3		
55	83.4	yes	108		0.2		abc
55	83.4	yes	107		0.2		abc
55	83.4	no	150		0.5		
55	83.4	no	150		0.5		
55	83.4	no	86	n/a	0.5		abc
55	83.4	no	152	0	0.4		abc
55	83.4	no	151	0	0.4		no
55	83.4	no	86		0.5		
55	83.4	no	86		0.5		

D	A	bdr	on	off	sb	nw	abc
inch	dm²		W	W	W	W	
55	83.4	no	86		0.5		
55	83.4	no	86		0.5		
55	83.4	no	85		0.24		
55	83.4	no	85		0.3		
55	83.4	no	85		0.24		
55	83.4	no	112		0.3		
55	83.4	no	112		0.3		
55	83.4	no	112		0.3		
55	83.4		110		0.5		
55	83.4		110		0.5		
55	83.4		110		0.5		
55	83.4		155		0.5		
55	83.4		115	0.3	0.5	1.2	cps
55	83.4		115	0.3	0.5	1.2	cps
55	83.4		130	0.25	0.5	1.2	abc
55	83.4		130	0.25	0.5	1.2	abc
55	83.4		129	0.25	0.5	1.2	abc
55	83.4		130	0.25	0.5	1.2	abc
55	83.4		130	0.25	0.5	1.2	abc
55	83.4		112	0.25	0.5	1.2	abc
55	83.4		106		0.15		abc
55	83.4		169		0.3		
55	83.4		131		0.5		
55	83.4		169				
55	83.4		100.3		0.5		
55	83.4		100.3		0.5		
50	68.9	yes	93	n/a	0.5	n/a	no
50	68.9	yes	110	n/a	0.5		
50	68.9	yes	92	n/a	0.5	3	abc
50	68.9	yes	61	n/a	0.3	n/a	no
50	68.9	yes	83	0.3	0.5	1	
50	68.9	yes	82	0.3	0.5	1	
50	68.9	yes	82	0.3	0.5	1.2	
50	68.9	yes	96	0.3	0.5	1.2	
50	68.9	yes	96	0.3	0.5	1.2	
50	68.9	yes	88	0.3	0.5	1.2	
50	68.9	yes	88	0.3	0.5	1.2	
50	68.9	yes	88	0.25	0.5	0.7	abc
50	68.9	no	130		0.5		
50	68.9	no	80		0.3		
50	68.9	no	80		0.25		
50	68.9	no	80		0.25		
50	68.9	no	93		0.3		
50	68.9	no	93		0.3		
50	68.9		93	0.25	0.5	1.2	abc
50	68.9		84	0.25	0.5	1.2	abc
50	68.9		84	0.25	0.5	1.2	abc

D	A	bdr	on	off	sb	nw	abc
inch	dm²		W	W	W	W	
49	66.2	yes	75	n/a	0.3	0.8	
49	66.2	yes	85	n/a	0.3	0.8	
49	66.2	yes	85	n/a	0.3	0.8	
49	66.2	yes	85	n/a	0.3	0.8	
49	66.2	yes	74	n/a	0.3	0.8	
49	66.2	yes	74	n/a	0.3	0.8	
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	90	n/a	0.5	n/a	no
49	66.2	yes	130		0.5		
49	66.2	yes	130		0.5		
49	66.2	yes	102	n/a	0.5	3	abc
49	66.2	yes	85	n/a	0.5	3	abc
49	66.2	yes	85	n/a	0.5	3	abc
49	66.2	yes	85	n/a	0.5	3	abc
49	66.2	yes	85	n/a	0.5	3	abc
49	66.2	yes	85	n/a	0.5	3	abc
49	66.2	yes	83	n/a	0.5	2	no
49	66.2	yes	83	n/a	0.5	2	no
49	66.2	yes	83	n/a	0.5	2	no
49	66.2	yes	83	n/a	0.5	2	no
49	66.2	yes	83	n/a	0.5	2	no
49	66.2	yes	83	n/a	0.5	2	no
49	66.2	yes	80	n/a	0.5	3	abc
49	66.2	yes	80	n/a	0.5	3	abc
49	66.2	yes	80	n/a	0.5	3	abc
49	66.2	yes	80	n/a	0.5	3	abc
49	66.2	yes	80	n/a	0.5	3	abc
49	66.2	yes	90	n/a	0.5	*	abc
49	66.2	yes	90	n/a	0.3	n/a	abc
49	66.2	yes	99	n/a	0.3	n/a	abc
49	66.2	yes	99	n/a	0.3	n/a	abc
49	66.2	yes	91	n/a	0.3	n/a	abc

D	A	bdr	on	off	sb	nw	abc
inch	dm²		W	W	W	W	
49	66.2	yes	71	n/a	0.5		
49	66.2	yes	115	0	0.3		abc
49	66.2	yes	117	0	0.3		abc
49	66.2	yes	85	0.3	0.5	1.2	cps
49	66.2	yes	70		0.3		
49	66.2	yes	97		0.2		abc
49	66.2	yes	96		0.2		abc
49	66.2	no	130		0.5		
49	66.2	no	71	n/a	0.5		
49	66.2	no	69	n/a	0.5		abc
49	66.2	no	71		0.5		
49	66.2	no	69		0.5		
49	66.2	no	69		0.5		
49	66.2	no	69		0.5		
49	66.2		84	0.3	0.5	1.2	cps
49	66.2		84	0.3	0.5	1.2	cps
49	66.2		93	0.3	0.5	1.2	abc
49	66.2		93	0.3	0.5	1.2	abc
49	66.2		90		0.2		abc
48	63.5	no	106	0	0.4		abc
48	63.5		121		0.5		
45	55.8	yes	110		0.5		
43	51.0	yes	64	n/a	0.3	0.8	
43	51.0	yes	70	n/a	0.3	0.8	
43	51.0	yes	70	n/a	0.3	0.8	
43	51.0	yes	70	n/a	0.3	0.8	
43	51.0	yes	63	n/a	0.3	0.8	
43	51.0	yes	63	n/a	0.3	0.8	
43	51.0	yes	63	n/a	0.3	0.8	
43	51.0	yes	95	n/a	0.5	n/a	abc
43	51.0	yes	71	n/a	0.5	n/a	no
43	51.0	yes	71	n/a	0.5	n/a	no
43	51.0	yes	110		0.5		
43	51.0	yes	70	n/a	0.5	3	abc
43	51.0	yes	70	n/a	0.5	3	abc
43	51.0	yes	70	n/a	0.5	3	abc
43	51.0	yes	70	n/a	0.5	3	abc
43	51.0	yes	65	n/a	0.5	2	no
43	51.0	yes	65	n/a	0.5	2	no
43	51.0	yes	65	n/a	0.5	2	no
43	51.0	yes	65	n/a	0.5	2	no
43	51.0	yes	65	n/a	0.5	2	no
43	51.0	yes	65	n/a	0.5	2	no
43	51.0	yes	82	n/a	0.5	3	abc
43	51.0	yes	82	n/a	0.5	3	abc
43	51.0	yes	82	n/a	0.5	3	abc
43	51.0	yes	82	n/a	0.5	3	abc

D	A	hdr	On	off	sb	nw	abc
inch	*dm²*		W	W	W	W	
43	51.0	yes	82	n/a	0.5	3	abc
43	51.0	yes	77	n/a	0.3	n/a	abc
43	51.0	yes	77	n/a	0.3	n/a	abc
43	51.0	yes	43	n/a	0.3	n/a	no
43	51.0	yes	93	0	0.43		abc
43	51.0	yes	95	0	0.43		abc
43	51.0	yes	55		0.29		
43	51.0	yes	91		0.15		abc
43	51.0	yes	91		0.15		abc
43	51.0	no	100		0.5		
43	51.0	no	110		0.5		
43	51.0	no		n/a	0.5		abc
43	51.0	no	54	n/a	0.5		abc
43	51.0	no	54		0.5		

D	A	hdr	on	off	sb	nw	abc
inch	*dm²*		W	W	W	W	
43	51.0	no	54		0.5		
43	51.0	no	54		0.5		
43	51.0		86	0.3	0.5	1.2	abc
43	51.0		86	0.3	0.5	1.2	abc
43	51.0		82		0.15		abc
43	51.0		64		0.5		
40	44.1	yes	61	n/a	0.5	n/a	no
40	44.1	yes	61	n/a	0.5	n/a	no
40	44.1	yes	61	n/a	0.5	n/a	no
40	44.1	yes	61	n/a	0.5	n/a	no
40	44.1	yes	63	n/a	0.5	n/a	no
40	44.1	yes	63	n/a	0.5	n/a	no
40	44.1	yes	63	0.3	0.5	1.2	cps
40	44.1	yes	63	0.3	0.5	1	cps

D	A	hdr	on	off	sb	nw	abc
inch	*dm²*		W	W	W	W	
40	44.1	yes	84	0.3	0.5	1.2	cps
40	44.1	yes	84	0.3	0.5	1.2	cps
40	44.1	no	63	n/a	0.5		abc
40	44.1	no	81	0	0.4		abc
40	44.1	no	62		0.3		
40	44.1	no	62		0.3		
40	44.1		68	0.3	0.5	1.2	cps
40	44.1		68	0.3	0.5	1.2	cps
40	44.1		74	0.3	0.5	1.2	abc
40	44.1		74	0.3	0.5	1.2	abc
40	44.1		65	0.3	0.5	1.2	abc
40	44.1		65	0.3	0.5	1.2	abc
40	44.1		100		0.5		
40	44.1		84		0.5		

HD 1080

75	155.1	no	163	n/a	0.5	2	no
65	116.5	no	123	n/a	0.5	2	no
65	116.5		125	0.2	0.3	0.7	abc
55	83.4	no	82	n/a	0.3	0.8	
55	83.4	no	82	n/a	0.3	0.8	
55	83.4	no	70	n/a	0.5	n/a	no
55	83.4	no	70	n/a	0.5	n/a	no
55	83.4	no	70	n/a	0.5	n/a	no
55	83.4	no	66	n/a	0.5	n/a	no
55	83.4	no	66	n/a	0.5	n/a	no
55	83.4	no	66	n/a	0.5	n/a	no
55	83.4	no	66	n/a	0.5	n/a	no
55	83.4	no	66	n/a	0.5	n/a	no
55	83.4	no	75	n/a	0.5	2	no
55	83.4	no	75	n/a	0.5	2	no
55	83.4	no	75	n/a	0.5	2	no
55	83.4	no	86	n/a	0.5	n/a	
55	83.4	no	86	n/a	0.5		abc
55	83.4	no	86		0.5		
55	83.4	no	85		0.3		
55	83.4	no	85		0.3		
55	83.4	no	85		0.3		
55	83.4		87	0.2	0.2		cps
55	83.4		91	0.2	0.3	0.7	abc
55	83.4		91	0.2	0.3	0.7	abc
55	83.4		91	0.25	0.3		abc
55	83.4		99		0.3		
50	68.9	no	72	n/a	0.5	2	no
50	68.9	no	72	n/a	0.5	2	no
50	68.9	no	72	n/a	0.5	2	no
50	68.9	no	71	n/a	0.5		

50	68.9		75	0.2	0.3	0.7	cps
50	68.9		75	0.2	0.3	0.7	abc
50	68.9		75	0.2	0.3	0.7	abc
50	68.9		63	0.3	0.3		abc
50	68.9		90		0.5		
49	66.2	yes	63	n/a	0.5	3	no
49	66.2	yes	63	n/a	0.5	3	no
49	66.2	yes	63	n/a	0.5	3	no
49	66.2	yes	60	n/a	0.5	3	no
49	66.2	yes	60	n/a	0.5	3	no
49	66.2	yes	60	n/a	0.5	3	no
49	66.2	no	69	n/a	0.3	0.8	
49	66.2	no	69	n/a	0.3	0.8	
49	66.2	no	69	n/a	0.3	0.8	
49	66.2	no	62	n/a	0.5	n/a	no
49	66.2	no	62	n/a	0.5	n/a	no
49	66.2	no	62	n/a	0.5	n/a	no
49	66.2	no	59	n/a	0.5	n/a	no
49	66.2	no	59	n/a	0.5	n/a	no
49	66.2	no	59	n/a	0.5	n/a	no
49	66.2	no	59	n/a	0.5	n/a	no
49	66.2	no	59	n/a	0.5	n/a	no
49	66.2	no	77	n/a	0.5	n/a	no
49	66.2	no	110		0.5		
49	66.2	no	61	n/a	0.5	1.5	no
49	66.2	no	61	n/a	0.5	1.5	no
49	66.2	no	61	n/a	0.5	1.5	no
49	66.2	no	61	n/a	0.5	1.5	no
49	66.2	no	61	n/a	0.5	1.5	no
49	66.2	no		n/a	0.5		
49	66.2	no	69		0.5		

49	66.2	no	69		0.5		
49	66.2	no	48		0.3		
49	66.2		45	n/a	0.3	n/a	
49	66.2		69	0.2	0.2		cps
48	63.5	no	58	n/a	0.5	1	no
48	63.5	no	46	n/a	0.5	1.5	no
48	63.5	no	65		0.3		
48	63.5		85		0.5		
43	51.0	yes	51	n/a	0.5	3	no
43	51.0	yes	51	n/a	0.5	3	no
43	51.0	yes	51	n/a	0.5	3	no
43	51.0	no	51	n/a	0.3	0.8	
43	51.0	no	51	n/a	0.3	0.8	
43	51.0	no	54	n/a	0.3	0.8	
43	51.0	no	42	n/a	0.5	n/a	
43	51.0	no	54	n/a	0.5	n/a	no
43	51.0	no	54	n/a	0.5	n/a	no
43	51.0	no	54	n/a	0.5	n/a	no
43	51.0	no	54	n/a	0.5	n/a	no
43	51.0	no	54	n/a	0.5	n/a	no
43	51.0	no	53	n/a	0.5	1.5	no
43	51.0	no	53	n/a	0.5	1.5	no
43	51.0	no	53	n/a	0.5	1.5	no
43	51.0	no	53	n/a	0.5	1.5	no
43	51.0	no	55	n/a	0.5	2	no
43	51.0	no	55	n/a	0.5	2	no
43	51.0	no	55	n/a	0.5	2	no
43	51.0	no		n/a	0.5	n/a	
43	51.0	no	54	n/a	0.5		
43	51.0	no	37		0.5		
43	51.0	no	54		0.5		

HD 1080 (continued)

D	A	bdr	on	off	sb	nw	abc
inch	*dm²*		*W*	*W*	*W*	*W*	
43	51.0	no	54		0.5		
43	51.0		55		0.12		abc
42	48.6		55		0.5		
40	44.1	yes	48	n/a	0.5	3	no
40	44.1	yes	48	n/a	0.5	3	no
40	44.1	yes	48	n/a	0.5	3	no
40	44.1	yes	48	n/a	0.5	n/a	no
40	44.1	yes	48	n/a	0.5	n/a	no
40	44.1	yes	48	n/a	0.5	n/a	no
40	44.1	no	56	n/a	0.5	n/a	no
40	44.1	no	70		0.5		
40	44.1	no	48	n/a	0.5	1	no
40	44.1	no	44	n/a	0.5	1.5	no
40	44.1	no	48	n/a	0.5	n/a	no
40	44.1	no	48	n/a	0.5		
40	44.1	no	48	n/a	0.5	n/a	
40	44.1	no	61	0	0.38		abc
40	44.1	no	48		0.5		
40	44.1	no	48		0.5		
40	44.1	no	46		0.3		
40	44.1	no	46		0.3		
40	44.1	no	54		0.29		
40	44.1	no	48		0.3		
40	44.1	no	48		0.3		

D	A	bdr	on	off	sb	nw	abc
inch	*dm²*		*W*	*W*	*W*	*W*	
40	44.1	no	48		0.3		
40	44.1	no	48		0.3		
40	44.1	no	45		0.3		
40	44.1	no	45		0.3		
40	44.1	no	46		0.3		
40	44.1	no	45		0.3		
40	44.1	no	46		0.3		
40	44.1	no	46		0.3		
40	44.1		60		0.5		
40	44.1		44	0.3	0.5	1	cps
40	44.1		49	0.2	0.3	0.7	cps
40	44.1		42	0.2	0.2		cps
40	44.1		48	0.3	0.3		cps
40	44.1		49	0.2	0.3	0.7	abc
40	44.1		49	0.2	0.3	0.7	abc
40	44.1		49	0.2	0.3	0.7	abc
40	44.1		42	0.3	0.3		abc
40	44.1		58		0.45		
32	28.2	no	36	n/a	0.3	0.8	no
32	28.2	no	41	n/a	0.5	n/a	no
32	28.2	no	41	n/a	0.5	n/a	no
32	28.2	no	41	n/a	0.5	n/a	no
32	28.2	no	41	n/a	0.5	n/a	no
32	28.2	no	41	n/a	0.5	n/a	no

D	A	bdr	on	off	sb	nw	abc
inch	*dm²*		*W*	*W*	*W*	*W*	
32	28.2	no	42	n/a	0.3	n/a	no
32	28.2	no	40	n/a	0.5	1.5	no
32	28.2	no	40	n/a	0.5	1.5	no
32	28.2	no	40	n/a	0.5	1.5	no
32	28.2	no	38	n/a	0.5	1.5	no
32	28.2	no	34	n/a	0.3	n/a	abc
32	28.2	no	31	n/a	0.5		
32	28.2	no	42	0	0.4		abc
32	28.2	no	44	0	0.4		abc
32	28.2	no	40	0	0.4		abc
32	28.2	no			0.5		
32	28.2	no	31		0.5		
32	28.2		33	0.3	0.3		cps
32	28.2		45	0.3	0.3		abc
32	28.2		41		0.1		abc
32	28.2		40		0.5		
23.6	15.4		24		0.5		
22	13.3	no	22		0.3		
22	13.3	no	22		0.3		
22	13.3		22	n/a	0.5		
22	13.3		22		0.5		
22	13.3		22		0.5		
21.5	12.7		22		0.5		
21.5	12.7		22		0.5		

HD 720

D	A	bdr	on	off	sb	nw	abc
32	28.2	yes	41	n/a	0.5	3	no
32	28.2	yes	41	n/a	0.5	3	no
32	28.2	yes	41	n/a	0.5	3	no
32	28.2	yes	41	n/a	0.5	n/a	no
32	28.2	yes	41	n/a	0.5	n/a	no
32	28.2	yes	41	n/a	0.5	n/a	no
32	28.2	no	29	n/a	0.3	n/a	no
32	28.2	no	37	n/a	0.5	n/a	no
32	28.2	no	31	n/a	0.3	n/a	no
32	28.2	no	35	n/a	0.5	1	no
32	28.2	no	35	n/a	0.5	1	no
32	28.2	no	35	n/a	0.5	1	no
32	28.2	no	35	n/a	0.5	n/a	no
32	28.2	no	41	n/a	0.5		
32	28.2	no	32	n/a	0.5		
32	28.2	no	31		0.5		
32	28.2	no	31		0.5		
32	28.2	no	31		0.5		
32	28.2	no	31		0.5		
32	28.2	no	31		0.5		

D	A	bdr	on	off	sb	nw	abc
32	28.2	no	31		0.5		
32	28.2	no	31		0.5		
32	28.2	no	31		0.5		
32	28.2	no	31		0.3		
32	28.2	no	31		0.3		
32	28.2	no	31		0.3		
32	28.2	no	31		0.3		
32	28.2	no	31		0.3		
32	28.2	no	31		0.3		
32	28.2	no	43		0.29		
32	28.2	no	31		0.3		
32	28.2	no	31		0.3		
32	28.2	no	31		0.3		
32	28.2	no	31		0.3		
32	28.2	no	30		0.3		
32	28.2	no	30		0.3		
32	28.2	no	30		0.3		
32	28.2	no	26		0.3		
32	28.2	no	26		0.3		
32	28.2		40		0.5		
32	28.2		39	0.3	0.5	1	cps

D	A	bdr	on	off	sb	nw	abc
32	28.2		32	0.3	0.3		cps
32	28.2		41	0.3	0.3		abc
32	28.2		35		0.5		
31.5	27.4		39		0.5		
31.5	27.4		39		0.5		
28	21.6	no	21	n/a	0.3	n/a	no
28	21.6	no	25	n/a	0.5	n/a	no
28	21.6	no	19	n/a	0.5	n/a	abc
28	21.6	no	25		0.5		
28	21.6	no	17		0.3		
28	21.6	no	17		0.3		
28	21.6	no	38		0.3		
28	21.6	no	17		0.3		
28	21.6		32		0.5		
27.5	20.8		31		0.5		
24	15.9	no	26	n/a	0.3	n/a	no
24	15.9	no	19	n/a	0.5	n/a	no
24	15.9	no	19	n/a	0.5		
24	15.9	no	19	n/a	0.5		
24	15.9	no	19		0.5		
24	15.9	no	19		0.5		

D	A	hdr	on	off	sb	nw	abc
inch	dm²		W	W	W	W	
HD 720 (continued)							
24	15.9	no	19		0.5		
24	15.9	no	19		0.5		
24	15.9	no	19		0.5		
24	15.9	no	25		0.3		
24	15.9	no	25		0.3		
24	15.9	no	25		0.3		
24	15.9	no	25		0.3		
24	15.9		17	0.25	0.25		cps
24	15.9		17	0.25	0.25		abc
24	15.9		19		0.5		
19	9.4		17		0.45		
19	9.4		17		0.45		
16	6.7		14		0.45		
16	6.7		14		0.45		

EU TELEVISION DATABASE, January 2018 (source: VHK 2018)

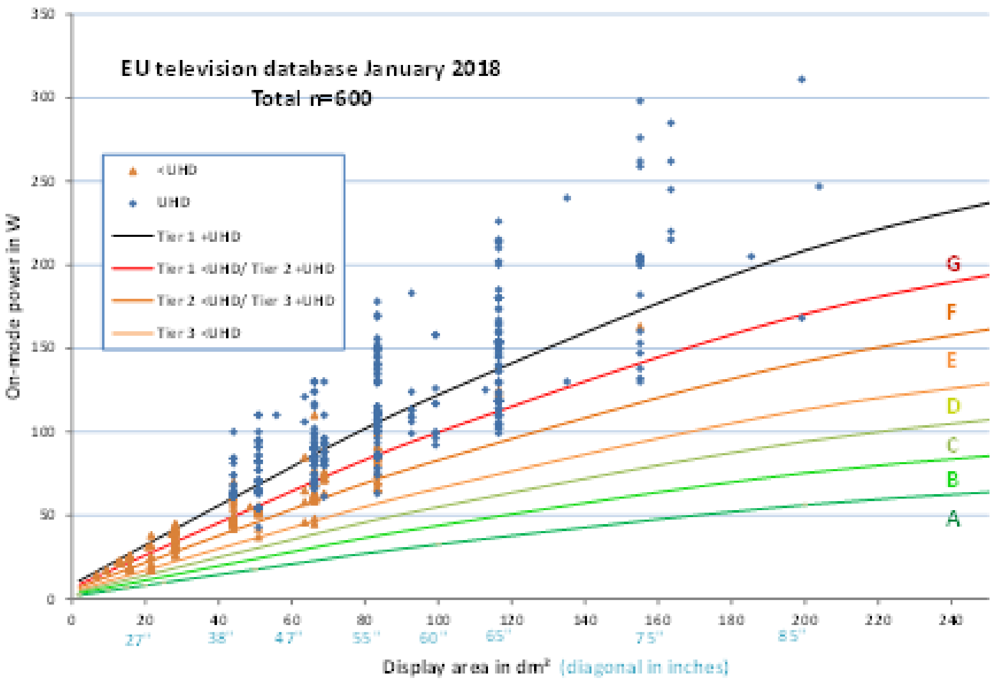


Figure 13.1: Proposed Energy Label and Ecodesign limits versus Dec. 2017 TV models on-line available

EU ENERGY STAR DATABASE

Table 13.1: EU Energy Star. Computer monitors compliant with specifications Version 7 (2016-2017)

	Nr. of models *#*	Reso-lution (mega pixels) *MP*	Diagonal Screen Size *inch*	Screen Area *dm^2*	On-Mode Power *W*	Specific power/ area *W/dm ²*	EEI new proposal	Off mode Power *W*	Standby Power *W*
UHD									
2017	26	9.26	29.09	23.42	35.44	1.57	**1.10**	0.26	0.39
2016	28	8.56	29.73	22.32	31.81	1.46	**1.01**	0.26	0.39
2015	9	8.29	29.60	24.64	32.59	1.35	**0.96**	0.31	0.38
2014	5	8.30	26.96	19.85	30.51	1.55	**1.06**	0.25	0.44
All	**68**	**8.77**	**29.26**	**22.87**	**33.21**	**1.49**	**1.04**	**0.27**	**0.39**
<UHD & >HD									
2017	54	3.31	27.05	19.82	21.33	1.07	**0.74**	0.23	0.33
2016	69	3.05	26.16	18.84	20.73	1.27	**0.76**	0.26	0.36
2015	8	3.00	24.49	16.93	20.20	1.19	**0.79**	0.26	0.42
2014	12	3.38	27.25	20.36	24.18	1.19	**0.82**	0.31	0.48
<=2013	11	2.68	25.73	18.31	20.65	1.11	**0.76**	0.28	0.35
All	**154**	**3.14**	**26.44**	**19.17**	**21.18**	**1.18**	**0.76**	**0.25**	**0.36**
HD									
2017	175	2.09	24.11	16.29	15.99	1.00	**0.65**	0.23	0.33
2016	303	2.10	23.77	15.89	15.82	1.01	**0.65**	0.20	0.29
2015	63	2.09	22.98	14.68	15.55	1.07	**0.68**	0.23	0.58
2014	32	2.07	23.67	15.53	16.09	1.05	**0.68**	0.26	0.34
<=2013	76	2.09	23.28	15.05	15.67	1.05	**0.68**	0.24	0.32
All	**649**	**2.09**	**23.72**	**15.77**	**15.83**	**1.02**	**0.66**	**0.22**	**0.33**
<HD									
2017	27	1.17	17.81	9.13	9.47	1.07	**0.56**	0.20	0.28
2016	78	1.37	19.27	10.96	11.51	1.07	**0.61**	0.19	0.30
2015	16	1.34	19.59	10.83	11.87	1.10	**0.64**	0.20	0.27
2014	9	1.33	18.28	10.20	11.63	1.14	**0.64**	0.23	0.26
<=2013	50	1.43	19.85	11.57	12.20	1.06	**0.63**	0.22	1.19
All	**180**	**1.35**	**19.19**	**10.80**	**11.44**	**1.07**	**0.61**	**0.20**	**0.54**
Total	1051	2.55	23.70	15.87	16.99	1.08	0.69	0.22	0.38

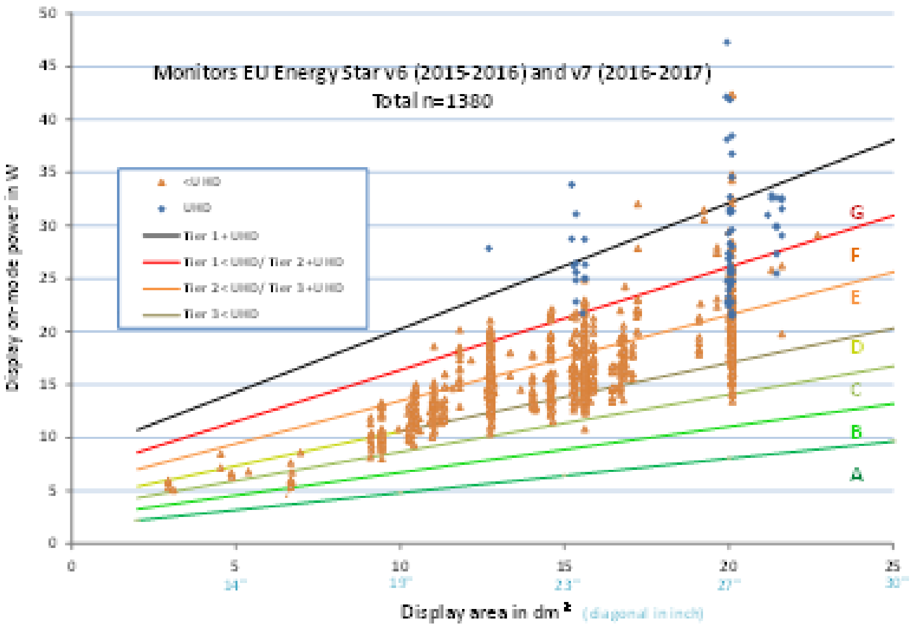


Figure 13.2: Proposed Energy Label and Ecodesign limits versus Energy Star compliant computer monitor models in the EU Energy Star database 2014-2017.

The following tables summarise the model characteristics of computer monitors in the EU Energy Star database for specification V6.0 (2014-2016) and V7.0 (2014-today). Data were extracted from www.eu-energystar.org in January 2018.

Note that per 20 February 2018 the US-EU International Agreement on the Energy Star for Office Equipment elapsed. This database is thus the most recent but also the last database of its kind.

Table 13.2: EU Energy Star, monitors compliant with specifications V. 6 (2014- 2016)

	Nr. of models #	Reso-lution (mega pixels) MP	Diagonal Screen Size inch	Screen Area dm^2	On-Mode Power W	Specific power/ area W/dm^2	EEI new proposal	Off mode Power W	Standby Power W
UHD									
2016	5	8.33	27.84	21.41	32.61	1.48	1.04	0.20	0.37
2015	37	8.64	29.57	25.56	39.05	1.64	1.14	0.29	0.45
2014	22	8.59	28.72	23.05	42.91	1.91	1.33	0.33	0.49
<=2013	3	8.29	27.77	21.53	60.47	2.88	1.95	0.32	0.72
All	67	8.59	29.08	24.24	40.79	1.77	1.23	0.30	0.47
<UHD & >HD									
2016	12	3.91	30.86	23.32	33.03	1.39	0.99	0.31	0.48
2015	56	3.54	29.91	22.71	31.90	1.42	0.99	0.30	0.42
2014	44	3.64	28.38	21.22	32.96	1.53	1.06	0.31	0.45
<=2013	31	3.52	27.91	20.55	36.27	1.76	1.21	0.33	0.51
All	143	3.60	29.08	21.84	33.27	1.53	1.06	0.31	0.45
HD									
2016	60	2.08	27.45	23.03	28.30	1.23	0.83	0.22	0.30
2015	286	2.08	30.22	28.88	41.49	1.34	0.94	0.23	0.33
2014	222	2.09	31.15	30.63	44.64	1.33	0.95	0.24	0.37
<=2013	505	2.08	27.26	22.88	33.01	1.37	0.92	0.24	0.40
All	1073	2.08	28.86	26.09	37.41	1.34	0.93	0.24	0.37
<HD									
2016	11	1.17	19.00	10.06	13.13	1.31	0.73	0.30	0.34
2015	55	1.26	19.13	10.71	12.94	1.22	0.69	0.19	0.26
2014	74	1.49	19.32	10.79	14.11	1.30	0.73	0.22	0.45
<=2013	216	1.48	19.96	11.52	14.64	1.27	0.74	0.20	0.28
All	356	1.44	19.67	11.20	14.22	1.27	0.73	0.20	0.32
Total	1639	2.34	26.89	22.41	32.15	1.36	0.91	0.24	0.37

Table 13.3: EU Energy Star,. monitors compliant with specifications V. 6 and 7 combined (2014-2016)

	Nr. of models #	Reso-lution (mega pixels) MP	Diagonal Screen Size inch	Screen Area dm^2	On-Mode Power W	Specific power/ area W/dm^2	EEI new proposal	Off mode Power W	Standby Power W
UHD									
2017	26	9.26	29.09	23.42	35.44	1.57	1.10	0.26	0.39
2016	33	8.53	29.45	22.19	31.93	1.46	1.01	0.25	0.39
2015	46	8.57	29.58	25.38	37.78	1.59	1.11	0.29	0.43
2014	27	8.53	28.39	22.45	40.61	1.84	1.28	0.31	0.48
<=2013	3	8.29	27.77	21.53	60.47	2.88	1.95	0.32	0.72
All	135	8.68	29.17	23.55	36.97	1.63	1.14	0.28	0.43
<UHD & >HD									
2017	54	3.31	27.05	19.82	21.33	1.07	0.74	0.23	0.33
2016	81	3.17	26.86	19.50	22.55	1.29	0.80	0.27	0.38
2015	64	3.48	29.24	21.99	30.44	1.39	0.97	0.30	0.42
2014	56	3.58	28.13	21.04	31.08	1.46	1.01	0.31	0.45
<=2013	42	3.30	27.34	19.96	32.18	1.59	1.09	0.31	0.47
All	297	3.36	27.71	20.45	27.00	1.35	0.91	0.28	0.41
HD									
2017	175	2.09	24.11	16.29	15.99	1.00	0.65	0.23	0.33
2016	363	2.09	24.38	17.07	17.88	1.04	0.68	0.20	0.29
2015	349	2.08	28.91	26.32	36.81	1.29	0.89	0.23	0.38
2014	254	2.08	30.20	28.73	41.04	1.30	0.92	0.24	0.36
<=2013	581	2.08	26.74	21.85	30.74	1.33	0.89	0.24	0.39
All	1722	2.09	26.93	22.20	29.28	1.22	0.83	0.23	0.35
<HD									
2017	27	1.17	17.81	9.13	9.47	1.07	0.56	0.20	0.28
2016	89	1.34	19.24	10.85	11.71	1.09	0.63	0.21	0.31
2015	71	1.28	19.24	10.73	12.69	1.19	0.67	0.19	0.26
2014	83	1.47	19.20	10.73	13.84	1.28	0.72	0.22	0.43
<=2013	266	1.47	19.94	11.53	14.18	1.23	0.72	0.20	0.45
All	536	1.41	19.51	11.07	13.28	1.20	0.69	0.20	0.39
Total	2690	2.42	25.65	19.86	26.23	1.25	0.82	0.23	0.37

COMPUTER MONITOR TESTING INTERTEK 2017

In 2017 and in a contract for the EC, Intertek tested 30 state-of-the-art computer monitors with the aim to identify possible problems in including monitors (not just televisions) in the proposed Commission Regulation on electronic displays.[15]

The final test included 11 models with UHD resolution (3840 x 2180 pixels = 8.37 MP), 8 models with HD resolution (1920x1080=2.1 MP) or lower and 11 models with a resolution between HD and UHD. In the latter category 9 models with aspect ratios of 2.4:1 for wide formats, 7 of them 'curved' are found. All the other monitors have a 16:9 aspect ratio and are, with one exception, not curved but flat.

The average resolution of the test population is 5.1 MP (3073 x 1571 pixels) at an average screen diagonal of 28.2 inch (71 cm) and average surface of 21.3 dm2.

Following manufacturer's instructions and pre-sets, only 10 out of 30 models (3 UHD, 7 below UHD) meet the Commission's proposed relevant EEI level. This is shown in the graph below

[15] VHK et al., Supporting the Commission with testing the energy consumption of computer displays in light of the update of data for the review of the Ecodesign and Energy Labelling Regulations on electronic displays, Final Report, Dec. 2017. Tests were done by Intertek. The test results were analysed by Robert Harrison Associates Ltd.. Technical project leader was Viegand Maagøe and contract manager for the consortium that did this assignment for the European Commission was VHK.

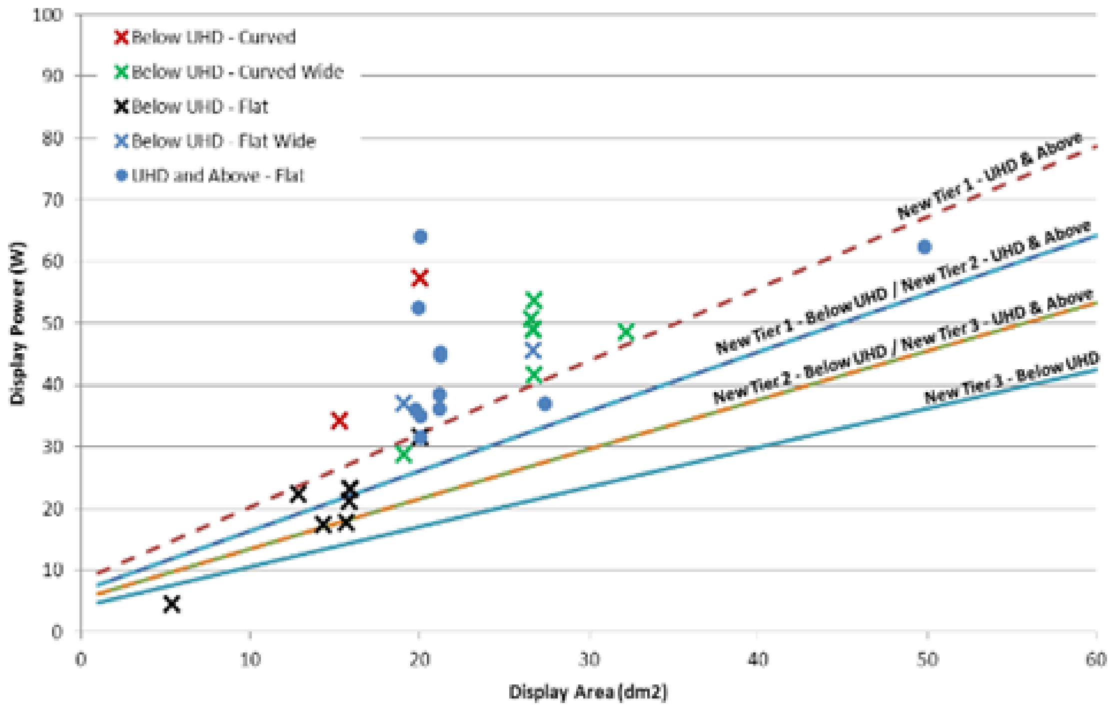


Figure 13.3: All monitor test data results: Average power and display area coordinates vs EEI requirements

However, the average home-mode (test) peak luminance is 267cd/m², while the average maximum peak luminance of the test population is 296 cd/m². This means the measurements are done at 90% of the maximum peak luminance, while testing at 65% would be allowed. Given the fact that over 80% of a display's energy input is used to generate light this can make a large difference.

Hence, the test report indicates that with some detailed attention to factory-set luminance levels, at least 19 out of 30 models (5 UHD, 14 below UHD) would pass. In table 1 VHK has added tentative values, based on the assumption that 80% of a display's energy input is used to generate light/luminance. [16]

Average UHD screen peak luminance is close to 330 cd/m²; for HD peak luminance is around 250 cd/m2. This means a factor of ~1.3 between UHD and HD luminance. The difference between UHD and HD minimum energy requirement is 1.22. The average specific luminance in cd/W for UHD is similar to that of HD, both 1.6 cd/W (rounded).

The average on-mode power is 36.9 W and the average energy efficiency index EEI is 1.2. The average 'manual' standby or off mode power is 0.24 W, with only 1 model using more than 0.5W. The standby power after an auto power down (APD) is 0.47 W, with 6 out of 30 models exceeding 0.5W.

Only 2 out of 30 models featured automatic brightness control (ABC). In both cases the ABC control characteristics is acceptably progressive but should start at a much higher ambient light level. Overall, the ABC test results support the argument that the ABC characteristics could mirror that for TVs.

[16] Pers. comm. Robert Harrison, Jan. 2018. Note that the light output in one direction can be given in luminance in cd/m2 or 'nits'

External AC-to-DC external power supplies (EPS) with a product specific DC interface connection (i.e. not a standardised DC interface such as USB) were found on 14 out of 30 models. All of these monitors have power requirements compatible with USB C power delivery (PD) Profiles 1 to 5 (10 to 100W) and with DC modification they could operate with a standard EPS.

Table 13.4: Computer monitors test Intertek/Harrison 2017 (n=30)

Test results Intertek/Harrison																	VHK additional			
Sample	Mega Pixel (HxV)	Res. Pixels Horiz. H	Res. Pixels Vertical V	Nominal Diagonal inch	Nominal Diagonal cm	Aspect Ratio	Display ***	Measured Image Area (dm²)	Lmax = Max. Peak Lum. (cd/m²)	Ltest = Default Peak Lum. (cd/m²)	Ptest = On-Mode power (W)*	(W)*	APD-Standby (W)*	EPS**	EEI	Compliance	P65% = power (W) at L=65% of max	EEI at L=65% max	Compliance at L=65% max	Specific Luminance cd/W
ED01	8.3	3840	2160	28	71	16:9	F	21.2	267	266	45.1	0.3	0.5	Y	1.47	FAIL	32.6	1.07	PASS	1.3
ED03	8.3	3840	2160	28	71	16:9	F	21.2	292	292	44.7	0.3	0.4	N	1.45	FAIL	32.2	1.06	PASS	1.4
ED08	8.3	3840	2160	27	68	16:9	F	19.7	328	328	35.9	0.3	0.3	N	1.24	FAIL	25.8	0.90	PASS	1.8
ED09	8.3	3840	2160	27	68	16:9	F	19.9	301	300	52.4	0.4	0.4	N	1.78	FAIL	37.9	1.29	FAIL	1.1
ED13	8.3	3840	2160	32	81	16:9	F	27.4	247	247	35.6	0.2	0.2	Y	0.96	PASS	25.6	0.70	PASS	1.9
ED20	8.3	3840	2160	43	10	16:9	F	49.8	342	342	56.3	0.2	0.3	N	0.93	PASS	40.5	0.67	PASS	3.0
ED28	8.3	3840	2160	28	71	16:9	F	21.1	318	209	39.0	0.2	0.3	N	1.28	FAIL	38.7	1.27	FAIL	1.1
ED29	8.3	3840	2160	28	71	16:9	F	21.1	304	277	36.1	0.2	0.2	Y	1.18	FAIL	28.5	0.94	PASS	1.6
ED30	8.3	3840	2160	27	68	16:9	F	20.0	427	224	31.4	0.3	0.3	N	1.07	PASS	34.6	1.18	FAIL	1.4
ED31	8.3	3840	2160	27	68	16:9	F	20.0	485	277	64.0	0.2	0.2	N	2.16	FAIL	68.1	2.29	FAIL	0.9
ED32	8.3	3840	2160	27	68	16:9	F	20.0	303	276	34.8	0.3	0.3	Y	1.19	FAIL	27.6	0.95	PASS	1.6
ED16	6.1	3840	1600	38	96	2.4:1	CW	26.7	294	294	45.6	0.3	0.7	Y	1.08	PASS	32.8	0.91	PASS	1.7
ED14	5.0	3440	1440	34	86	2.4:1	CW	26.8	302	302	50.2	0.3	1.3	Y	1.37	FAIL	36.1	0.99	PASS	1.6
ED17	5.0	3440	1440	34	86	2.4:1	CW	26.7	348	343	44.5	0.2	0.6	Y	1.22	FAIL	32.5	0.90	PASS	2.1
ED18	5.0	3440	1440	34	86	2.4:1	CW	26.7	273	273	46.0	0.3	0.6	Y	1.26	FAIL	33.2	0.91	PASS	1.6
ED23	5.0	3440	1440	34	86	2.4:1	CW	26.6	309	309	50.6	0.3	0.3	N	1.39	FAIL	36.4	1.01	PASS	1.6
ED26	5.0	3440	1440	34	86	2.4:1	FW	26.7	272	220	45.4	0.4	0.4	N	1.24	FAIL	39.7	1.09	PASS	1.3
ED24	3.7	2560	1440	27	68	16:9	C	20.0	424	399	57.3	0.3	0.8	Y	1.93	FAIL	44.0	1.49	FAIL	1.4
ED27	3.7	2560	1440	27	68	16:9	F	20.0	234	201	31.6	0.3	0.3	N	1.08	PASS	26.3	0.91	PASS	1.3
ED04	2.8	2560	1080	29	74	2.4:1	CW	19.0	302	272	24.7	0.2	0.8	Y	0.88	PASS	19.7	0.71	PASS	2.1
ED06	2.8	2560	1080	29	74	2.4:1	FW	19.1	312	312	37.0	0.2	0.3	Y	1.3	FAIL	26.6	0.95	PASS	1.6
ED15	2.8	2560	1080	34	86	2.4:1	CW	26.8	247	247	36.2	0.2	0.3	Y	0.99	FAIL	26.1	0.72	PASS	1.8
ED02	2.1	1920	1080	24	61	16:9	F	15.9	234	234	23.1	0.2	0.3	N	0.94	FAIL	16.6	0.69	PASS	1.6
ED05	2.1	1920	1080	24	61	16:9	F	15.9	289	289	23.1	0.2	0.2	N	0.94	FAIL	16.6	0.69	PASS	2.0
ED07	2.1	1920	1080	24	61	16:9	F	15.6	141	141	17.7	0.1	0.2	N	0.74	PASS	12.7	0.54	PASS	1.3
ED19	2.1	1920	1080	24	61	16:9	F	15.8	299	299	21.1	0.2	0.3	N	0.86	PASS	15.2	0.63	PASS	2.2
ED21	2.1	1920	1080	24	61	16:9	C	15.3	351	257	34.1	0.2	0.3	Y	1.4	FAIL	31.9	1.31	FAIL	1.2
ED22	2.1	1920	1080	22	56	16:9	F	12.8	257	257	22.3	0	0.2	N	1.04	FAIL	16.1	0.76	PASS	1.5
ED25	2.1	1920	1080	23	58	16:9	F	14.3	214	163	17.3	0.1	2.2	Y	0.76	PASS	15.7	0.70	PASS	1.4
ED12	1.4	1600	900	14	36	16:9	F	5.39	156	156	4.5	0.5	0.5	DC5	0.38	PASS	3.2	0.30	PASS	1.9
Avg.	**5.1**	**3037**	**1571**	**28**	**71**	**0.7**		**21.3**	**296**	**267**	**36.9**	**0.24**	**0.47**	**14=Y**	**1.18**		**29.1**	**0.95**		**1.61**
									ratio	*90%*				15=N						

*=*all stable*

**=*if EPS=Y then modifiable to standardised power (sample ED12 with EPS= DC5V is ready for USB)*

*** *F=Flat; C=Curved; FW=Flat Wide; CW=Curved Wide*

Note 1: All samples have LCD technology, they do NOT have 'HDMI CEC', but they DO have 'EDID active video all inputs'

*Note 2: P65%, on-mode power (W) at L=65% of Lmax is calculated as P65% = Ptest * {1 –[(Ltest/Lmax – 0.65)/0.35] x 0.28 }*

Note that factor 0.28 is 80% of 0.35

Annex 14: Background: Energy Flows, Luminance, HDR

1. ENERGY FLOWS

The Sankey diagram below was composed by VHK in the context of a technical assistance contract for this impact assessment. It is an estimate, with certain subjective aspects, of the energy flows in an LCD-LED electronic display. The aim is to illustrate that, viewing the display mainly from the perspective of a lamp and comparing to the theoretical minimum, the efficiency of the display is less than 1%. In other words, there is still ample room for innovation and improvement.

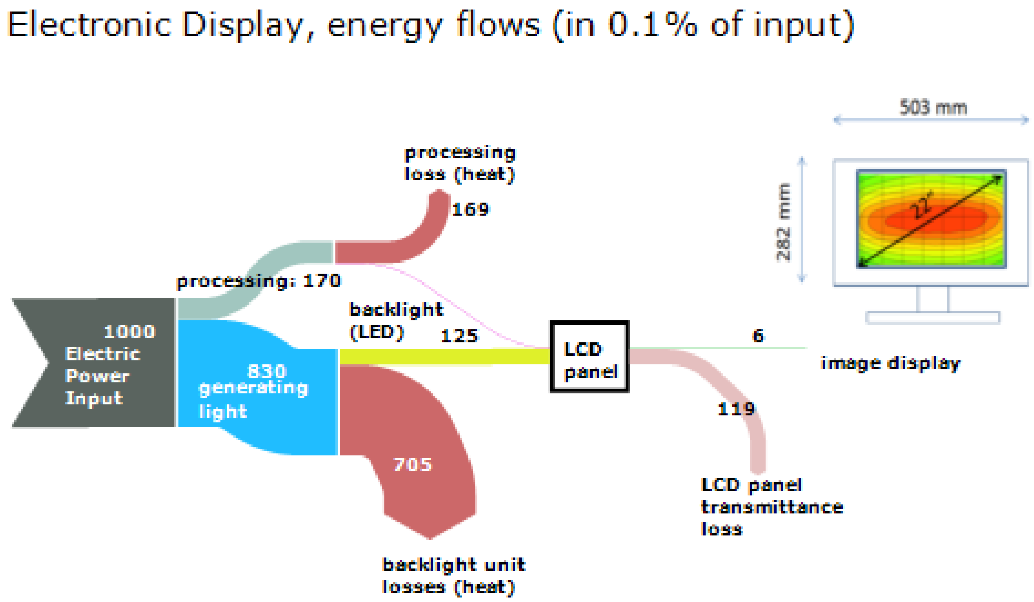


Figure 14.1: LCD-LED Electronic Display, energy flows in 0.1% of electric power input,(source: VHK 2018)

The diagram illustrates that over 80% of the electricity input goes to generate light and –not taking into account sound—only a small part goes to signal processing.

Starting point for the light generation is the LED backlight. The process to produce visible light through Light Emitting Diodes is called electroluminescence, the transformation of electrons into photons, using p and n junction of the diode. The radiometric efficiency, a.k.a. the external quantum efficiency *EQE*, involves the injection efficiency *IE*, i.e. the share of electrons injected in the active region of the diode, the internal quantum efficiency *IQE* of creating photons from the electrons and the extraction efficiency LEE of moving the photons outside the LED.

EQE=EI x IQE x LEE

The exact values of the separate efficiency values varies between 60 and 90%, depending on the various design parameters. The EQE will be around 40% for 110-120 lm/W.

The efficacy of light sources is commonly expressed in lm/W, i.e. lumen visible light output per Watt electricity input. Lumen is the physical radiant power, but corrected for the sensitivity of the human eye. The human eye is most sensitive to green (wavelength 550 nm).

The maximum theoretical efficacy of creating visible light from electricity is thus 683 lm/W at a monochromatic 'green' wave length of 555 nm. However, to create a full colour gamut also the other colours are necessary and then, depending on the spectrum realised --let us assume 'white'-- the white light efficacy drops by half to around 340 lm/W or less.

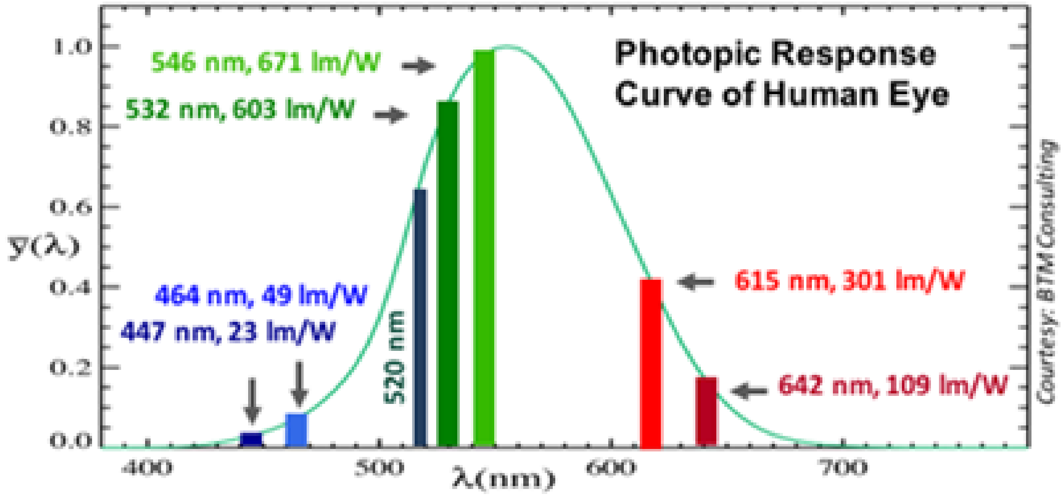


Figure 14.2: Photopic response to different light wavelengths in human eye (source: http://www.ledinside.com/news/2017/6/color_in_next_generation_micro_led_microdisplays).

The practical efficacy is lower because 1 W of physical radiant power cannot be converted loss-free into visible light. At the moment 240 lm/W, so a white light efficacy of 75%, is a value that is seen to be short-term achievable in literature and in laboratory settings.[17]

The best available LEDS in television backlight units (BLUs) have a white light efficacy around 200 lm/W. In computer monitors, typically a more low-end product than a television, the average value may be in the range of 100-150 lm/W. The Sankey-diagram, which is purely intended to be illustrative of the order of magnitude assumes 100 lm/W, so a white light efficacy of 29%.

This is a simplification, based on a test pattern with white light. In a movie, depending on the display technology, the efficacy of the backlight may vary with the colour-mix, even at the same luminance. This is certainly the case with OLEDs or in the future microled subpixels, but also with the more crude local dimming control the backlight colour mix can be set, e.g. with RGD LEDs. CREE 300 lm/W. Samsung 220 lm/W.

Table 14.1: Light Transmission of various LCD components

Polarizer	43%
Colour filters	25%
TFT aperture ratio	80%
Liquid crystal	95%
Analyzer	80%
Overall (colour LCD)	5%

Source: Pochi Yeh, Claire Gu, Optics of Liquid Crystal Displays, 2nd ed., 2010, John Wiley & Sons, Hoboken, New Jersey, USA.

[17] https://www.dial.de/en/blog/article/efficiency-of-ledsthe-highest-luminous-efficacy-of-a-white-led https://news.samsung.com/global/samsung-achieves-220-lumens-per-watt-with-new-mid-power-led-package (June 2017).

Once the light is produced it goes through a whole range of light guide optics, polarizers, colour filters, thin film transistor (TFT) ‘shutter’ arrays, liquid crystal panels, lenses, etc..

The table below, representing 2010 technology, estimates that overall in a colour LCD only 5% of the light input actually reaches the eyes of the users.

In recent years, according to Park et al. [18], there has been considerable improvements e.g. though reflective polarizers[19] such as 3M’s Vikuiti™ Dual Brightness Enhancement Film (DBEF) that can bring 30-50% improvement. However, it has to be rerecalled that the starting point, i.e. 5% transmittance, is low.

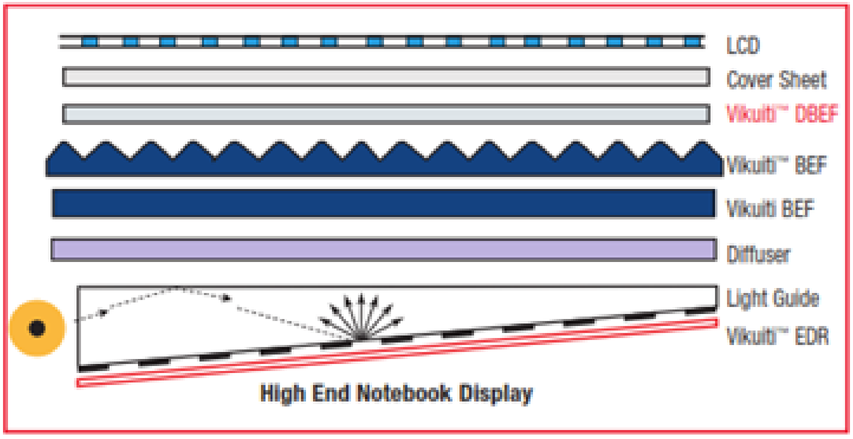


Figure 14.3: Built-up of LCD screen with reflective polarizer (source: 3M)

2. LUMINANCE

The biggest threat of HDR to energy use is that it might actually increase the need for a certain luminance level (expressed in cd/m^2 or ‘nits’), because it offers a larger brightness range when running the test video. Thus the importers claim that a generous efficiency allowance should be made for HDR in order not to deprive the European consumers of this new technology.

With a more sophisticated solution, i.e. an LED -TV with local dimming or an OLED TV, the size of the white rectangle does matter: A small white spot (e.g. a sun in the distance) might be as bright as 1400 cd/m^2, while a full-screen white rectangle only gives 350 cd/m^2. In fact, a good UHD/HDR television ‘only’ uses some 20% more than a HD/SDR television[20] when HDR content is displayed.

Given that 80% of the display’s energy input goes into generating light, the second most important performance parameter –after the surface area—is luminance (a.k.a. ‘brightness’). Luminance is measured in candela per square meter (cd/m^2) also known as ‘nits’. The candela is the luminous flow measured in one direction[21], i.e. for a display the direction is typically perpendicular to the screen. For testing, the first important question is the setting of the

[18] Won Young Park, Amol Phadke, Nihar Shah, Virginie Letschert, *Efficiency improvement opportunities in TVs: Implications for market transformation programs*, Lawrence Berkeley National Laboratory, Energy Policy 59 (2013) 361–372.
[19] A reflective polarizer recovers a certain type of polarized light, which cannot be transmitted through the rear polarizer of the LCD panel, by reflecting this portion of light back to the backlight unit and depolarizing it so that the light can be newly polarized to transmit back to the panel.
[20] SDR= Standard Dynamic Range
[21] Compare: ‘lumen’ is the space integral of the candelas in all directions.

luminance. In the EU proposal the setting is either ‘out of the box’ or the ‘home mode’, but perhaps more important is the boundary condition that the brightness should not be less than 65% of the ‘brightest possible setting’, i.e. usually the setting in a well-lit ambient a shop).

For luminance measurement the test pattern is important. In IEC 62087:2011 the luminance should be tested with a test pattern of three white bars [100% bright] on a black [0% bright] background. The Average Picture Luminance (APL) of this test pattern is around 50% and Jones and Harrison argued that this is too high for average video content and usually enough to trigger maximum (100%) brightness settings.[22] Therefore the newer IEC 62087:2015 standard proposes that the 10-minute video content that is used for on-mode power testing is also used for assessment of the luminance. The APL of this video-content is 34%.

Further confusion is added by the HDR standard that refers to the ‘maximum’ or peak luminance, expressed in cd/m2 or ‘nits’, of an electronic display. A higher peak brightness means the TV can make the picture look brighter, which can help with visibility in an ambient with lots of light and/or, or to make small highlights in the picture look good (which is important for HDR).

Testers of www.rtings.com recommend, for instance a brightly lit (indoor) ambient: over 400 cd/m2 in a test pattern with a 50% white window on a black background window. For HDR contrast over 1000 cd/m² in a 2% white window is considered good.

The UHD Alliance, an industry group comprising the likes of Dolby, LG, Netflix, Panasonic, Samsung and Warner Bros, writes in specifications for the award of the ‘Ultra HD Premium’ –which contain also demands e.g. on wider colour gamut WCG[23]-- that a UHD-TV peak luminance should either have a 1000-nit peak brightness and less than 0.05 nits black level or a 540-nit peak brightness and less than 0.0005 nits black level. The latter would typically apply to OLED-TVs, with pixels that can be ‘off’ (really black) while the OLED screens have problems to achieve the light levels of the (anorganic) LEDs.

‘Peak luminance’ is no longer well defined in standards, because for half of recent UHD-HDR televisions the peak luminance is now adapting, with local dimming enabled, to the brightness/size of the content. Figure 1 shows a comparison between ‘QLED’ (the latest series of Samsung LED TVs), OLED and LED.

[22] Jones, K., Harrison, R., The Impact of Changing TV technologies and Market Trends on the Energy Consumption on TVs and the need for a better TV Energy Test Method, 2012.

[23] Support 10-bit colour depth, BT.2020 colour space presentation, HDR (HDR 10 or Dolby Vision HDR), be capable of producing more than 90 per cent of the DCI P3 color standard and of course 4K resolution (3840 x 2160 pixels)

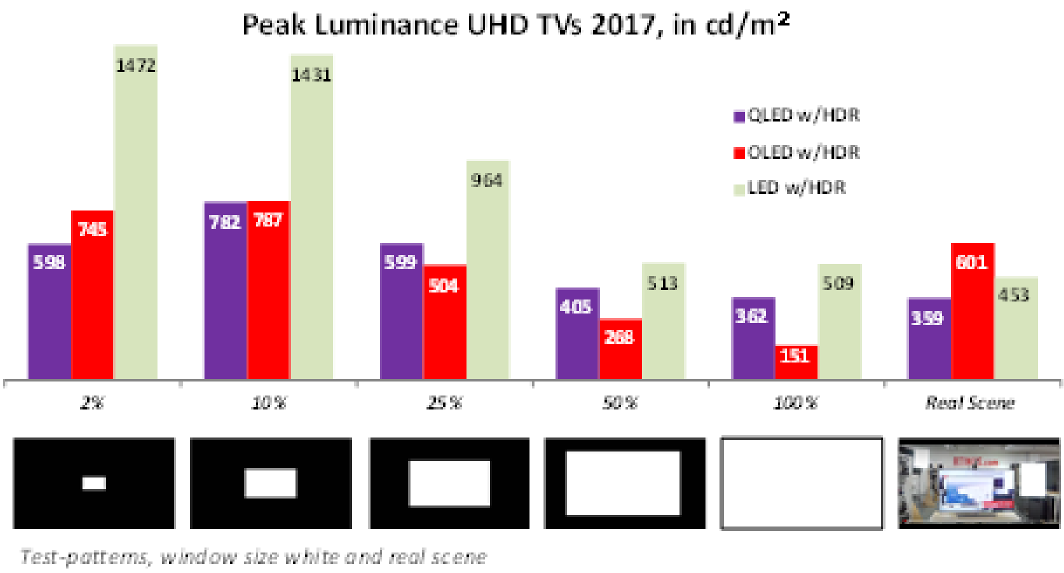


Figure 14.4: Peak luminance of typical QLED, OLED and LED UHD-HDR televisions 2017, in cd/m² at different test patterns= size of white window as % of the total surface (data: www.rtings.com, graph: VHK 2018)

If a scene contains only a small area of maximum brightness, the maximum luminance in that small surface, e.g. 2 or 10%, can be as high as 1400 nits. If the maximum brightness of the image applies to 50% or 100% of the screen area, then the peak luminance of the same device can be as low 350 nits.

Relevant definitions are

- **HDR Real Scene peak brightness:** The maximum luminosity the TV can obtain while playing a movie or while watching a TV show in HDR at a window size of 2%. Measured with local dimming and HDR signal. Good value: > 550 cd/m² Noticeable difference: 80 cd/m²
- **SDR (Standard Dynamic Range, i.e. not HDR) Real Scene peak brightness:** as above but with a non-HDR signal. Good value: > 300 cd/m² Noticeable difference: 30 cd/m²
- **HDR peak window 2/10/25/50/100%:** as Real Scene, but with a white test rectangle 2, 10, 25, 50, 100% of the window size, measured for a short time. The purpose is to test the variance in luminance over the full range of bright scenes, because many (9 out of 10) UHD TVs adapt the maximum luminance according to the size of the scene in order to keep the TV (including electronics and power supply) from being damaged. Tested with local dimming and HDR signal.
- **HDR sustained window 2/10/25/50/100%:** as HDR Peak Window, but after the luminance value has stabilised.
- **ABL: Automatic Brightness Limiting** is a feature that dims the maximum luminance of the TV when a large portion of the TV is displaying a bright colour. This is done to help prevent components used in the TV from being damaged when the TV makes the screen really bright across a wide amount of space. ABL is expressed as the standard deviation of the HDR sustained brightness, after linearizing for noticeable differences in luminosity. Good value: <0.07. Noticeable difference: 0.01. Relevant especially for games.

It may seem at first that LED TVs are incredibly far ahead. But the 'white window' numbers are far from being represented in a real viewing environment (as seen in the 'real scene' results). Even if OLEDs cannot reach the same peaks of brightness with testing slides, those synthetic measurements are a lot closer to reality. Both LED TVs can only get half or even a third as bright as their theoretical peak when watching a typical movie! The QLED TV is especially weak in this case since it can't even reach theoretical peaks higher than OLED. There is one important part that LED does undeniably do better. While OLED can get small highlights brighter than LEDs in real content, it also dims a lot more when watching a scene that is very bright throughout. For this reason, the LED TV edges it out since it can remain quite bright even while showing an entirely bright screen.

The following table shows the peak luminance results for 35 models and 107 screen sizes of 2017 UHD HDR televisions. The first 18 models (48 sizes), roughly half of the test population, showed large differences depending on the test pattern. For the other half of the population the values are within a small bandwidth.

The rting.com testers also did a similar test for 20 models of monitors, but there only one model showed (short-time) large luminance variations depending on test pattern.[24]

Overall it is difficult to draw a general conclusion, but especially the models in the top rows the peak luminance at 2-10% white windows are around 20-30% higher than what one could expect for the screen as a whole.

SDR luminance performance of computer monitors, in cd/m2 (source: rtings.com)

Product	Resolution		Peak luminance window size					Sustained HDR window size						
		Real Scene SDR	2%	10%	25%	50%	100%	2%	10%	25%	50%	100%	ABL score	score
BenQ Zowie XL2540	1920x1080	444	459	460	460	460	460	459	460	460	460	459	0	8.3
Dell U2715H	2560x1440	388	403	403	403	402	401	402	403	403	402	401	0	8.2
Dell U2515H	2560x1440	367	382	384	384	383	382	382	384	384	383	381	0	8.1
Dell U3417W	3440x1440	349	366	364	361	359	357	365	361	358	356	354	0	8.0
AOC AGON AG271QX	2560x1440	347	350	350	350	350	350	350	350	350	350	350	0	8.0
ASUS VG248QE	1920x1080	362	372	374	369	365	362	367	372	367	363	360	0	8.0
Samsung CHG70	2560x1440	352	571	576	376	380	381	374	299	315	316	309	0.03	8.0
ASUS PB277Q	2560x1440	344	357	357	357	356	357	357	356	357	356	356	0	8.0
*Samsung CHG90**	*3840x1080*	*331*	*610*	*611*	*489*	*331*	*333*	*315*	*278*	*300*	*303*	*293*	*0.04*	7.9
LG 27UD68P-B	3840x2160	313	327	328	329	329	329	243	239	251	285	327	0	7.6
Acer Predator XB271HU	2560x1440	286	314	314	314	314	313	314	314	314	314	313	0	7.5
HP V320	1920x1080	295	312	313	313	312	312	312	313	313	312	312	0	7.5
Dell U2717D	2560x1440	298	309	311	307	307	308	307	310	307	304	304	0	7.5
MSI Optix G27C	1920x1080	278	291	290	290	289	289	290	290	289	289	289	0	7.3
Samsung UE590	3840x2160	278	287	292	293	293	293	287	291	292	292	292	0	7.3
Dell S2716DG	2560x1440	275	288	288	288	288	288	284	286	286	286	287	0	7.3
LG 29UM69G-B	2560x1080	245	262	262	262	262	261	242	262	262	262	261	0	6.9
LG 34UC79G-B	2560x1080	222	249	249	249	249	249	210	176	190	199	199	0	6.5
Dell P2417H	1920x1080	220	230	231	230	230	229	228	231	230	229	227	0	6.4
Dell P2217H	1920x1080	205	217	218	218	218	218	216	217	218	218	218	0	6.2
Average		**303**	**342**	**343**	**325**	**317**	**316**	**308**	**302**	**305**	**306**	**307**	**0.00**	**7.48**

**=UHD and HDR support with local dimming (gaming monitor 27")*

[24] https://www.rtings.com/monitor/tests/picture-quality/peak-brightness

Television peak brightness in cd/m², UHD - HDR TVs 2017 (OLED when indicated; otherwise LED)

(source: https://www.rtings.com/tv/tests/picture-quality/peak-brightness)

			Peak luminance window size HDR					Sustained HDR window size						
Product	Sizes (inch diag)	Real Scene HDR	2%	10%	25%	50%	100%	2%	10%	25%	50%	100%	ABL	score
Sony X930E	55" 65"	1442	1159	1540	1027	866	764	1155	1510	1002	855	751	0.035	9.2
Sony Z9D	100" 65" 75"	1375	1316	1653	1357	906	678	1294	1607	1332	899	673	0.045	9.2
Sony X940E	75"	1184	1030	1177	1158	762	545	1017	1150	1147	761	543	0.042	9
Samsung Q9F	65" 75"	690	906	1410	1185	920	709	777	1204	1161	913	563	0.041	8.4
Sony X900E	49" 55" 65" 75"	546	883	820	585	529	531	871	780	575	526	525	0.033	7.7
LG C7 (OLED)	55" 65"	718	717	733	447	313	143	695	703	429	291	137	0.100	7.6
Samsung Q8C	55" 65" 75"	531	817	1061	758	493	481	519	690	699	492	479	0.026	7.6
LG B7A (OLED)	55" 65"	670	822	768	479	313	144	753	734	471	300	140	0.102	7.6
LG E7P (OLED)	55" 65"	689	681	732	399	285	132	656	689	394	279	131	0.101	7.5
Sony A1E (OLED)	55" 65" 77"	600	699	681	435	240	146	653	649	429	237	145	0.097	7.3
TCL P607	55"	489	327	515	683	623	566	323	512	681	620	563	0.041	7.3
Samsung Q7F	55" 65" 75"	419	741	921	683	460	459	469	640	652	460	458	0.026	7.2
LG UJ7700	49" 55" 60" 65"	446	647	640	528	433	426	638	634	526	431	424	0.028	7.2
Vizio M Series 2017	50" 55" 65" 70" 75"	407	628	793	774	431	353	615	774	760	425	350	0.05	7.1
Samsung MU8500	55" 65"	422	580	643	640	470	458	441	564	566	468	455	0.017	7.1
Samsung MU8000	49" 55" 65" 75" 82"	417	527	583	574	429	411	400	500	505	405	395	0.018	7
Samsung MU9000	55" 65" 75"	424	554	609	602	442	429	420	535	534	440	426	0.018	7
Vizio P Series 2017	55" 65" 75"	442	313	435	482	511	531	310	431	478	507	522	0.031	7
Sony X850E	65" 75"	395	429	425	422	419	417	427	424	421	418	417	0.001	6.8
Sony X800E	43" 49" 55"	395	403	437	437	437	436	402	437	436	435	435	0.005	6.8
LG SJ9500	65"	360	606	980	587	470	394	603	271	363	390	392	0.042	6.8
TCL C807	55" 65"	354	374	374	375	376	376	373	374	375	375	375	0	6.5
Samsung MU7000	40" 49" 55" 65"	338	198	365	362	361	362	196	359	358	358	358	0.041	6.3
Samsung MU6300	40" 43" 50" 55" 65" 75"	330	200	363	359	356	355	198	358	354	352	350	0.039	6.3
Samsung MU7600	49" 55" 65"	341	190	350	347	347	347	189	344	343	343	343	0.04	6.3
Sony X720E	43" 49" 55"	326	337	339	340	340	341	337	338	339	340	340	0.001	6.3
LeEco Super4	43" 55" 65"	284	331	329	328	329	330	331	329	328	329	330	0.001	6.1
LG UJ6300	43" 49" 55" 65"	297	319	319	318	318	318	317	318	317	317	317	0	6.1
Samsung MU6500	49" 55" 65"	310	189	348	347	347	347	189	344	344	344	344	0.041	6.1
Samsung MU6290	40" 43" 49" 55" 65" 75"	307	190	342	337	335	334	189	334	333	332	330	0.038	6.1
LG SJ8500	55" 65"	243	531	609	496	364	295	522	210	278	292	294	0.051	6
Samsung MU6100	58"	291	163	291	290	290	289	162	287	287	286	287	0.04	5.9
Sony X690E	50" 60" 70"	234	246	246	247	247	247	245	245	245	245	245	0	5.5
Vizio E Series 2017	50" 55" 60" 65" 70" 75" 80"	233	87	115	121	230	239	85	111	118	224	236	0.077	5
TCL S405	43" 49" 55" 65"	169	189	190	190	190	191	189	190	190	190	191	0.001	4.8
TOTAL/ Average	35 models, 107 sizes (40 to 80")	489	524	632	534	434	386	485	559	508	425	379	0.036	6.91

A first conclusion is that the content-based luminance variation, enabled through local dimming and/or active matrix in combination with rapid ex-ante image analysis, is a very useful feature for televisions to realise on one hand the UHD peak luminance requirements, even up to the UHD Premium level, and on the other hand keep the power consumption in check.

As such it can be expected to be incorporated in all the UHD models in a few years. This means that these models will be able to claim e.g. 1000 cd/m² HDR peak luminance (2% or 10% window), but still only use as much power as today's standard television featuring a 350-400 cd/m² peak luminance.

It also means that the currently proposed UHD versus HD limits, with a factor 1.2-1.25 correction, are not necessarily prohibiting the further development of better image quality.

As a final note it should be considered that the findings for peak luminance and picture quality relate to televisions, i.e. displays with a fairly dynamic content, viewed indoors from a distance of 2 to 5 meters. The findings are not necessarily transferable to computer (or similar) displays, i.e. displays with usually a relatively static content and viewed from a distance of 0.5 to 0.7 meters. In those cases the ergonomics (eye fatigue, general physical and mental fatigue) and the image retention or other detrimental technical effects will limit the peak luminance to current values (see table above). For instance, monitor manufacturers like EIZO advice to adjust 'white window' luminance to a level of 100-150 cd/m^2 in an office with normal brightness of 300-500 lux. [25] . The same source also mentions an increased flicker-effect at increased brightness setting for PWM-fed[26] monitors.

The luminance variation from a close distance, i.e. the ABL value, is not seen as a positive feature for monitors, especially not for gaming.

Indoor signage displays can be expected to follow the path of the UHD HDR television peak luminance settings for current TV sizes of up to 75-80". Even though peak luminance rates up to 2500 cd/m^2 can be found in advertisements, values of 1000-1400 cd/m^2 as found in the brightest UHD HDR televisions should be (more than) enough in signage practice. If anything, because the content is usually more static, the ex-ante image analysis of the display may reveal that certain static parts of the image should have less luminance to prevent image retention.

For outdoor signage displays, theatre displays, video walls, etc. the peak luminance requirements may be (much) higher than what can be found in normal televisions, with values of 5000 cd/m². Outdoor display technologies can be quite different from indoor displays. Whereas in televisions the OLED is the only active matrix currently available, in very large (outdoor) displays the active matrix is already now built from (inorganic) LEDs at the level of sub-pixels. In the near future the size of these pixels will be further reduced. For instance, at the international CES 2018 trade fair Samsung will present a demonstration of an active-matrix display with what it calls 'microleds' at the level of sub-pixels. It hopes to have this technology in the home TV in a few years, which is an important opportunity for energy saving. But to have this technology at mass-production prices also enables the introduction of high luminance (=high contrast) displays in outdoor applications. The challenge, both for industry and society in general, is to take care that the luminance of these future displays, and thereby their energy consumption, will be controlled smartly. This means an optimal ABC (Automatic Brightness Control) depending on the outdoors conditions (sunny, cloudy,

[25] http://www.eizo.com/library/basics/10_ways_to_address_eye_fatigue/#05

[26] Power supply with Pulse Width Modulation. The alternative is an 'analogue' AC-DC transformer ('DC' power supply). EIZO mentions that with a DC power supply the color reproduction declines at low brightness and brightness cannot be set very low and the price is higher.

day/night) , smart presence sensors (e.g. luminance increase when people get near, where relevant), simple time control (no working displays in closed metro, train stations, shopping malls, etc.).

Note that for signage displays in traffic applications there may be special requirements, e.g. on colour representation or font, that can be safety-related or are just legacy-related for a specific Member State.

3. PAPER-INK, E-INK OR ELECTRONIC PAPER NON-RETROILLUMINATED TECHNOLOGY.

A new generation of non-backlit signage displays may come to market: "paper-ink" or "electronic paper" big displays prototypes have been presented requiring a minimal amount of energy, just for updating the image displayed. Examples are SOOFA (http://www.soofa.co/soofa-sign/), Visionect (https://www.visionect.com/blog/42-inch-epaper-display/), CDS (http://crystal-display.com/cds-offering-development-kits-for-epaper/) or E Ink Corporation (https://www.youtube.com/watch?v=cxT6WvZvIEM). The energy required is so little that these displays can be completely wireless, e.g. powered by a battery and energy-harvested by a small photovoltaic panel.

4. AUTO BRIGHTNESS CONTROL (ABC)

ABC is an energy saving feature of a TV that uses a built-in light sensor to detect ambient light levels in the room and adjusts screen brightness for viewer comfort. Reduced light levels means reduced screen brightness and, consequently, energy savings.

The following chart provides an overview of the likely influence on energy use by activation of ABC control in some television (US market)

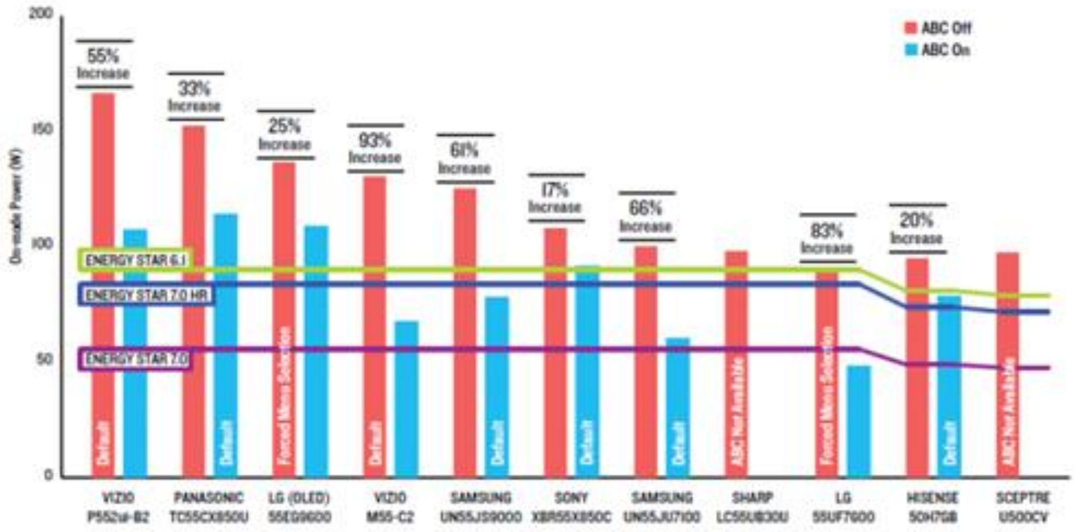


Figure 14.5: Comparison of 4K on-mode power use with ABC ON and OFF (Source: NRDC, https://www.nrdc.org/sites/default/files/uhd-tv-energy-use-report.pdf)

Figure 14.6, from a US DoE study, illustrates how a logarithmic response curve can get the idealised relationship between illuminance and luminance for the of human eye.

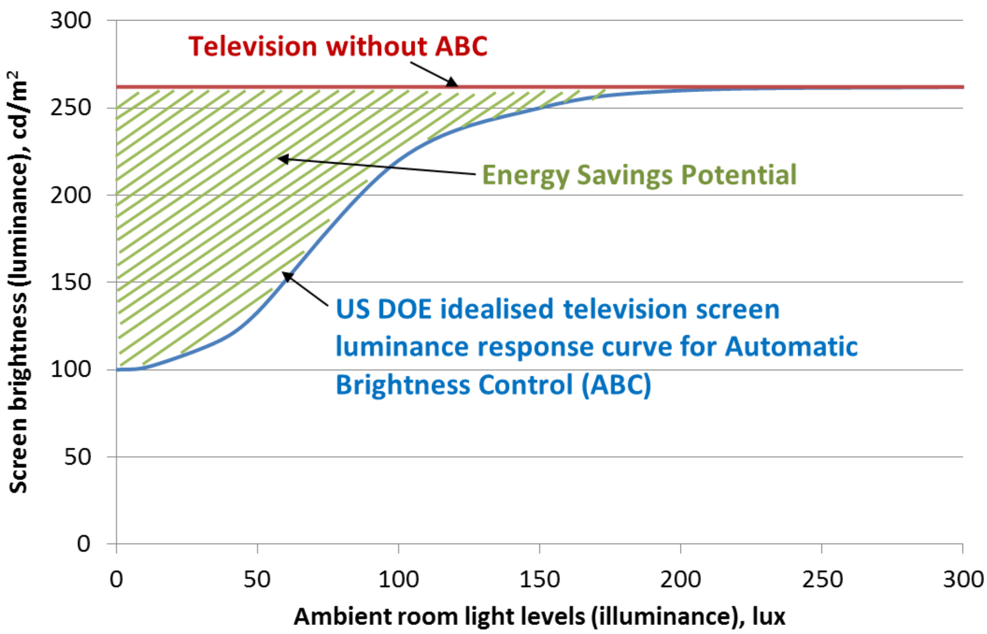


Figure 14.6: US DOE study, 2012 looking at the room illuminance levels and screen luminance. Found a logarithmic response curve of human eye – doubling of brightness perceived the same - 10 : 20 :: 100 : 200 (lux)

ABC implementation in displays, however, can deeply differ from the idealistic curve (Figure 14.7). An appripiate testing methos, consequently, is deemed as necessary.

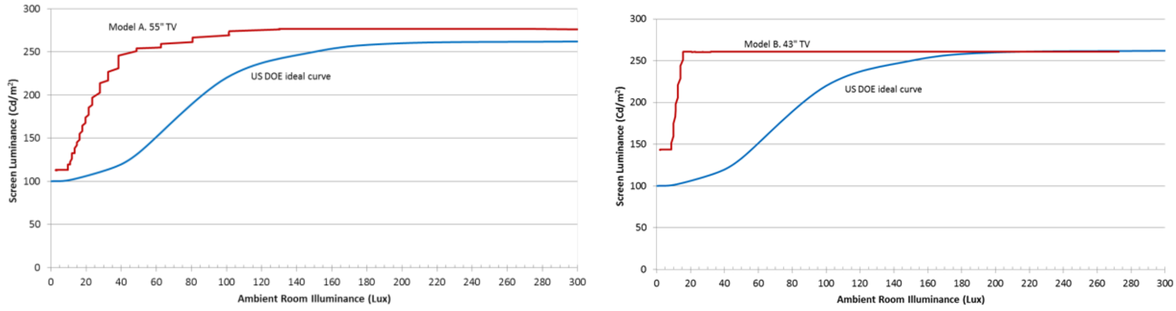


Figure 14.7: comparison of two displays with ABC to the ideal curve: is saves some energy, but is brighter (left) or does little to save, using a step function (right).

5. HIGH DYNAMIC RANGE (HDR)

The graphs below present the second-by-second power consumption of 7 different models of television displays on the market in 2017, all HDR-enabled.

The measures are taken while playing 4 different 10 minutes video loops. IEC EN 62087 is the original video test loop, in HD resolution, part of the standard currently used to measure the energy use as to be indicated on the current energy label.

STEP HD is an alternative video test loop using a different pattern and aiming at avoiding possible "defeat device" techniques and non realistic energy consumption declarations. STEP UHD and STEP UHD-HDR are the same alternative videos respectively in UHD resolution and, with HDR metadata in addition. It is surprising as different algorithm implementations can lead to so different energy use paths, with some implementations showing virtually no higher energy use and others over doubling it.

See also CLASP, ECOS, EEB, TopTen, (2015), and NRDC (2015).

IEC 62087 105 Watts

STEP HD 99 Watts

STEP UHD 99 Watts

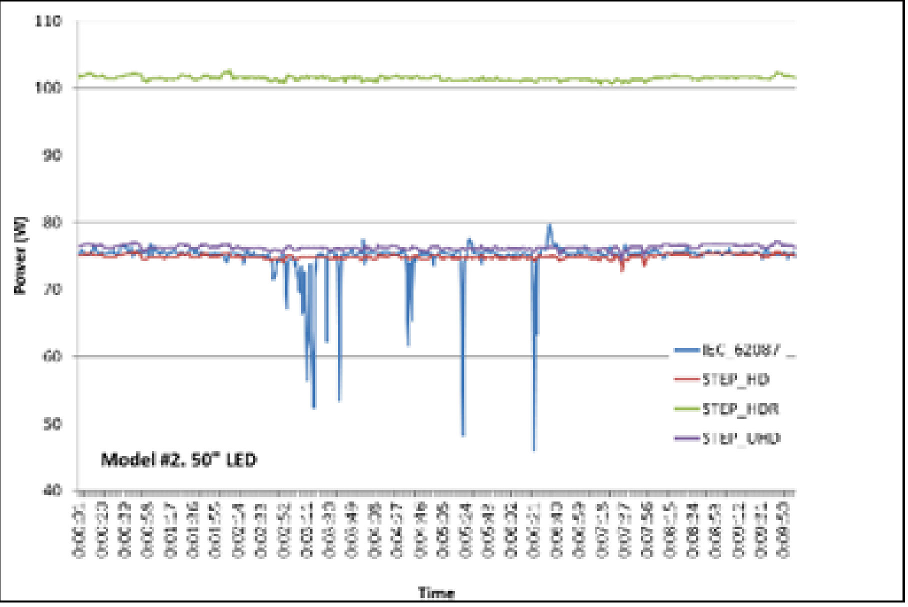
STEP UHD-HDR 157 Watts.

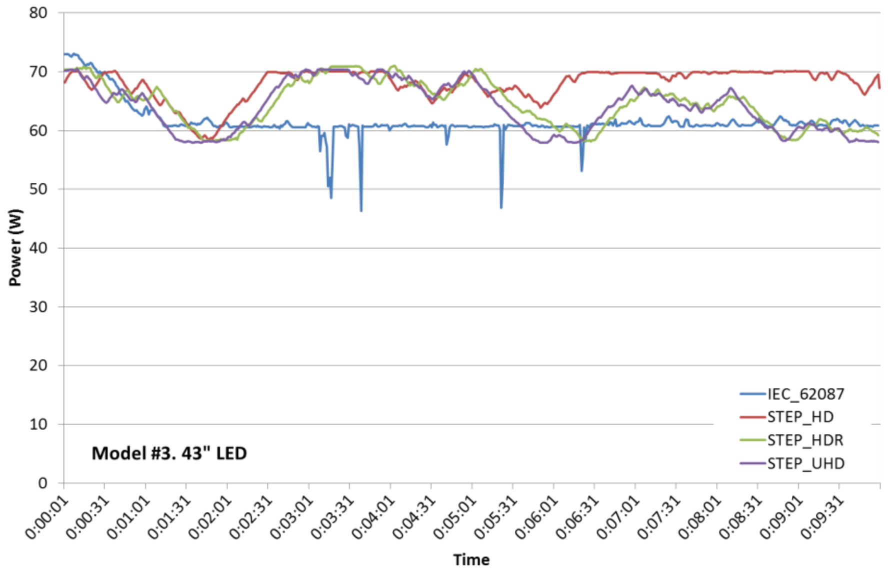
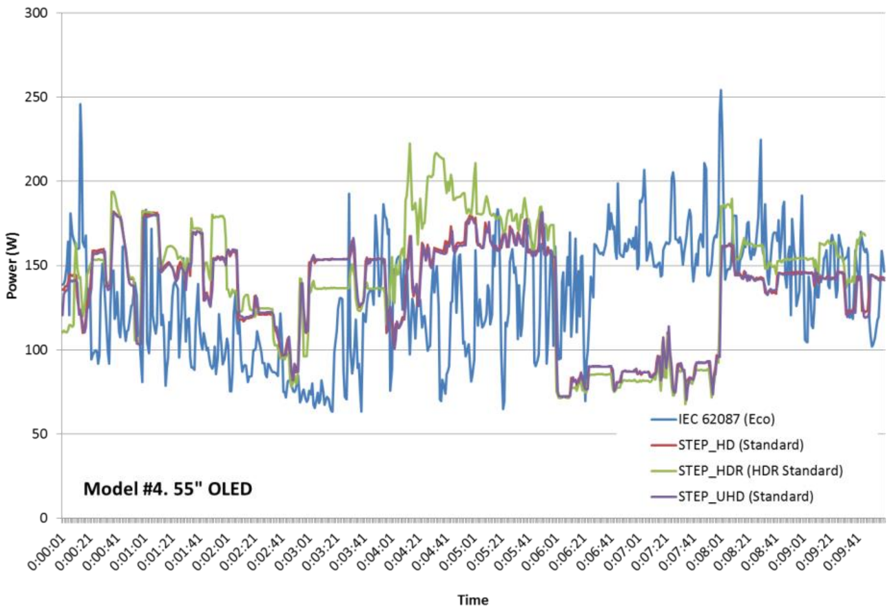
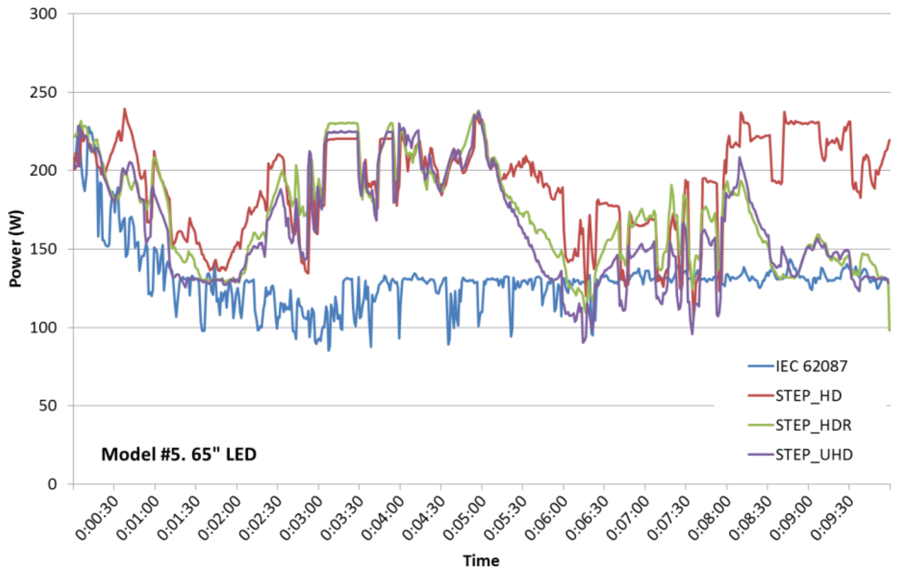
IEC 62087 75 Watts;

STEP HD 75 Watts;

STEP UHD 76 Watts; and

STEP UHD-HDR 101 Watts.



IEC 62087 62 Watts; STEP HD 68 Watts; STEP UHD 64 Watts; and STEP UHD-HDR 64 Watts.	
IEC 62087 132 Watts; STEP HD 134 Watts; STEP UHD 134 Watts; and STEP UHD-HDR 141 Watts.	
IEC 62087 130 Watts; STEP HD 191 Watts; STEP UHD 165 Watts; and STEP UHD-HDR 172 Watts.	

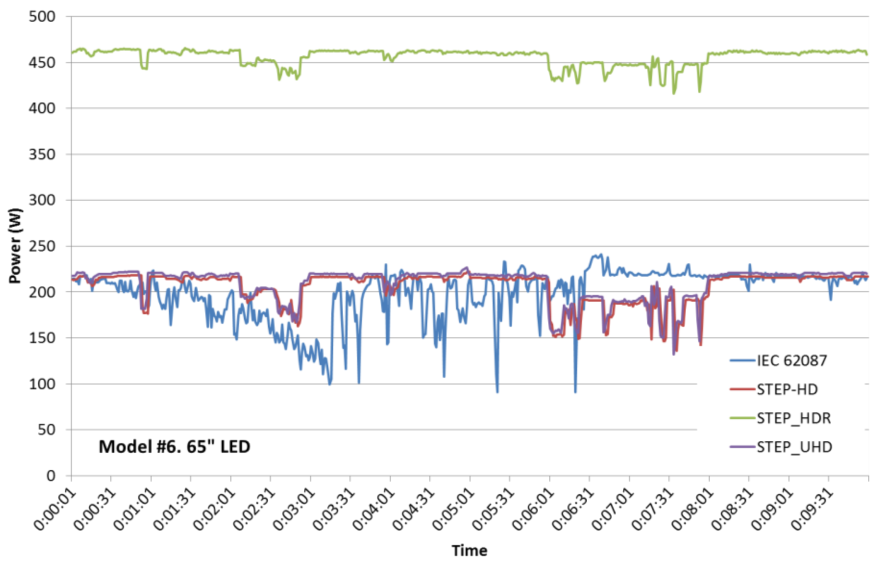
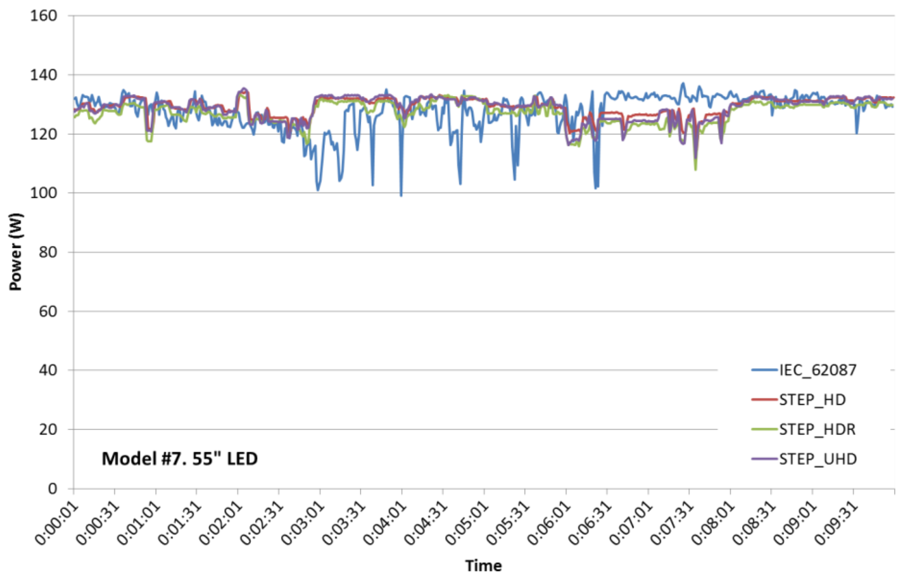
IEC 62087 199 Watts; STEP HD 206 Watts; STEP UHD 209 Watts; and STEP UHD-HDR 456 Watts.	
IEC 62087 128 Watts; STEP HD 129 Watts; STEP UHD 127 Watts; and STEP UHD-HDR 129 Watts	

Figure 14.8: Comparison of second-by-second power consumption of 7 different models of television displays on the market in 2017, all HDR-enabled (Source: Personal communication with CLASP Europe, April 2018: anonymised STEP project UHD-HDR television test results).

6. TECHNOLOGY OUTLOOK 2030

As regards the background on the improvements in the last 5 years, Won Young Park et al.(2013) give a very comprehensive overview of worldwide technologies, their costs and energy savings[27].

At least since the Consultation Forum in December 2014, manufacturers claimed energy allowances for HDR (High Dynamic Range) and for UHD. During the first year since being launched on the market, those models were undoubtedly using 50% more energy than SDR (Standard Dynamic Range) models and HD models. In the latest models, however, the high contrast range of HDR is implemented through "smart local dimming". , which may achieve 1400 cd/m2 luminance for a white surface that is 10-20% of the total, but will tune back to the ordinary 350 cd/m2 when the whole screen is white. In the Annex 14 a more comprehensive overview is given.

Another concern is how and if the OLED displays will hold up with much more stringent efficiency requirements. It is believed that there is still some room for improvement with this most recent display technology and thus that it might need more time.

To verify the current status of monitor energy use[28], the EC commissioned in 2017a study on 30 models. A discussion from that study can be found in the Annex 13.

In the next few years, a large improvement-step can be expected from 'microLEDs'. This is a LED-based technology which no longer works with a LED-backlight and masks/filters, but where each pixel is made of LED-subpixels. This self-emitting new technology can be compared to OLED: companies developing MicroLED promise features such as very high contrast, very deep blacks, fast response time, high brightness levels and low energy consumption. It can be expected that, at current luminance, the energy efficiency will increase by at least a factor 2.5 to 3. The picture quality in terms of contrast ratio and colour gamut, can be at least as good as with OLED. Already in 2012 Sony unveiled its industry first 55"Crystal LED TV prototype, followed by a commercial HD display module in 2016. In 2018 Samsung presented a 146" commercial UHD display called 'The Wall'. High-end consumer are expected from 2020, with more affordable versions to follow from 2021-2022.

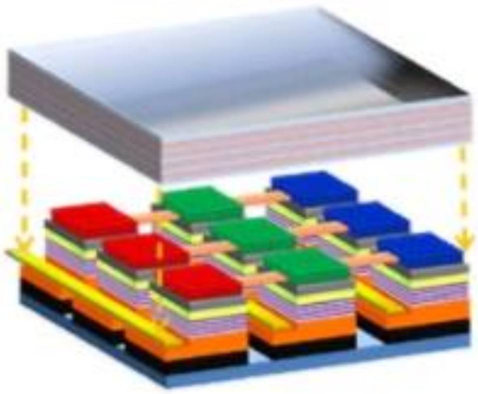


Figure 14.9: Basic example of microLEDs constituting a single pixel

With this technology it should be possible to go below the 0.3 W/dm², or about 15W on-mode power for a 43"(50 dm²) TV and 22 kWh/year. Below 50", a HD resolution might be more than sufficient for a great display that is also more environmentally friendly. Chances for microLEDs are looking good, but in the scenario calculation a slightly more conservative efficiency line for 2020-2030 will be followed considering that in the past new technologies such as Field Emission Display (FED) and Surface-conduction Electron-emitter Display (SED) were promised a great future but developments stopped in 2009.

[27] Won Young Park, Amol Phadke, Nihar Shah, Virginie Letschert, *Efficiency improvement opportunities in TVs: Implications for market transformation programs*, Lawrence Berkeley National Laboratory, Energy Policy 59 (2013) 361–372.

[28] Whilst data on TV energy use is widely available because of information requirements included in the current Ecodesign and Labelling Regulations, data on monitors is less easy to be found.

The Cinema in the Sihlcity shopping centre in Zurich is probably the first in Europe where laser projectors are replaced by a videowall of microLED signage display modules. The manufacturer claims up to 10 times the peak brightness of projectors, in a darker room, with impressive resolution level. Samsung acquired Yesco, a Utah-based company leading in the feld of microLED technology and is going to place on the market a " modular display", composed of elements of 37 inches each, with a resolution of 960x540 pixels, permitting to compose in a seamless surface of pixels, indoor or outdoor display screens of virtually any size.

7. FORMULA FOR CALCULATING ENERGY EFFICIENCY INDEX

The test procedures for energy efficiency of televisions stem from the 2008 state-of-the-art in resolution that was "Full HD" (1920x1080 pixels). The introduction of Ultra High Definition (UHD, 3840x2160 pixels) as well as the contrast ratio and colour gamut pertaining to ‘High Dynamic Range’(HDR) make it necessary to develop a new video test loop that can deliver an appropriate input-signal to test electronic displays and provide results closer to "real life".

The technology progress also influences the metrics of the limit-curves. In electronic displays the overall energy use is influenced mainly by two components:

- The display panel, with the associated backlighting (unless self emitting technologies such as OLED or Quantum Dots are used); the energy use is proportional to the display area and is influenced by the resolution level, luminosity level, etc
- The electronics to decode images and drive the pixels in the panel: the energy use is virtually independent from the size of the display panel and marginally influenced by the resolution level.

The current limit for on-mode power of televisions is linear, as in relatively small displays, the influence of the panel in respect to the electronics is comparable. However the market trends towards bigger and bigger panels make the linear curve not appropriate anymore and a curve is desirable. A hyperbolic tangent (tanh) has long been used in other labelling schemes such as Energy Star and is considered a more appropriate curve, especially for the largest displays on the market.

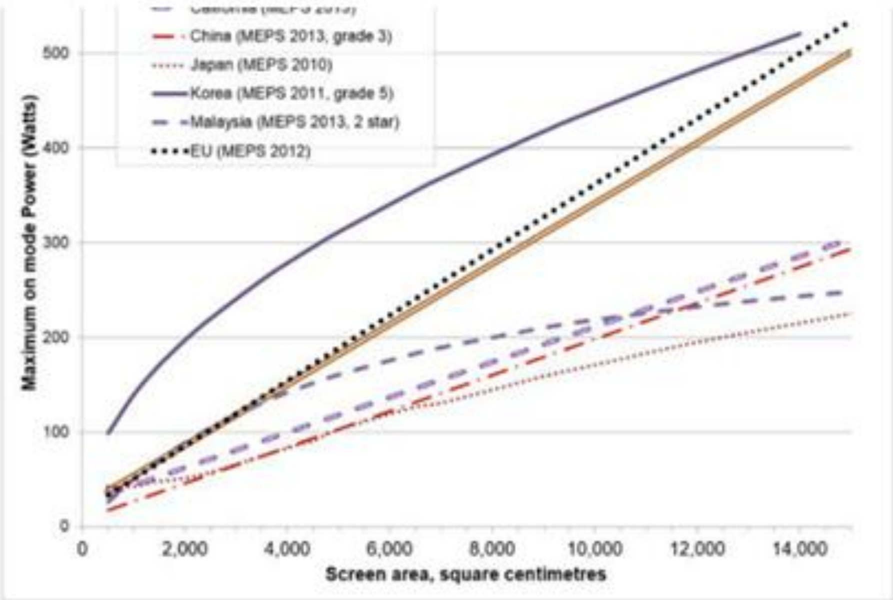


Figure 14.10: Maximum on-mode power limits in force compared in well-known international regulations (SEAD webinar 21 April 2015)

- Proposed On-Mode power demand limits for electronic displays are now expressed in the form of a formula where both the display area and the measured power are parameters. The formula uses a "*tanh*" curve that, contrary to the linear curve used in the Regulation currently in force, matches the non-linear relation between display area and power used that resulted from the analysis of the data on displays on the market[29]. Figure 6.17 shows the power consumption levels of electronic display models from the model database used for the impact assessment, compared with the requirements currently in force (Tier 2, brown line): the graph clearly shows how the efficiency levels for the biggest displays are far below the current requirements.
- The proposed formula is based on a similar ENERGYSTAR function but has been adapted to be used for all displays in the scope. To simplify compliance control, it does not consider the presence of a tuner, panel display technology or parameters other than the display area.

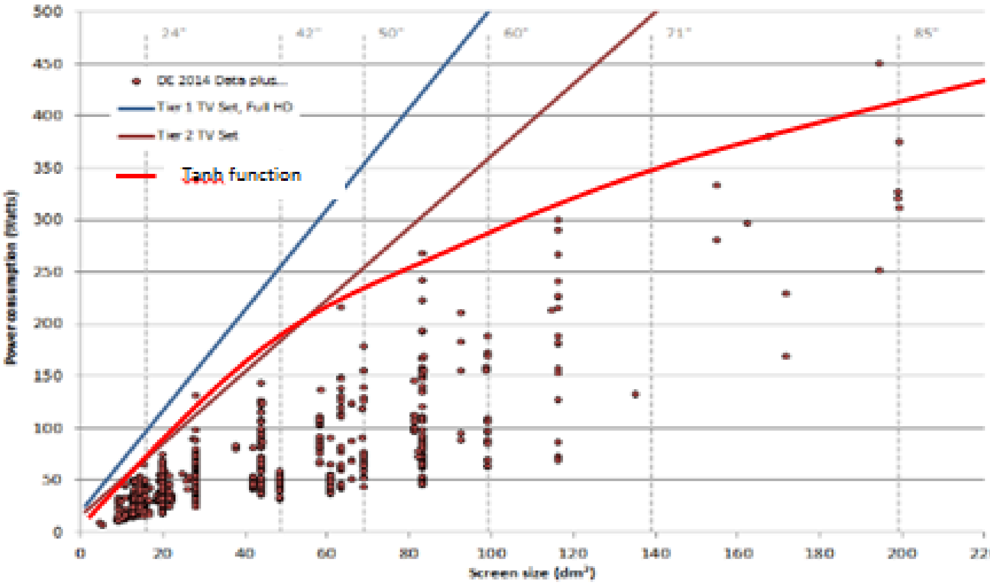


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Figure 14.11: Comparison between the 2014 data on display models data and requirements included in Tier1 and Tier 2 of the current ED regulation 642/2009 and a possible "tanh" curve.

The same function can be used in the Energy Labelling regulation, setting specific energy efficiency values (EEI) for different efficiency classes.

[29] Both data provided by industry and data autonomously collected.

Annex 15: Background: Circular economy and other non-energy impacts.

1. END-OF-LIFE, WEEE MASS FLOWS

Electronic displays are subject to WEEE Directive 2012/19/EU for products in Annex I, categories 3 (Consumer Electronics, including TVs) and 4 (ITT equipment, including monitors). For that reason Eurostat compiles statistics on the relevant mass flows. The most recent data are in the table below.

Table 15. 1. WEEE Eurostat env_wasleee, extract Feb. 2018 (VHK)

Consumer Electronics CE (75 wt% TV), in kt	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Products put on market	**1020**	**1191**	**954**	**955**	**841**	**723**	**634**	**738**	**:**
Waste collected	**347**	**450**	**536**	**601**	**645**	**624**	**:**	**613**	:
- waste collected from hh	340	441	541	618	653	626	596	583	:
- waste collected from others	8	10	13	9	12	13	:	30	:
- treated in MS	417	507	585	629	651	639	:	568	:
- treated in another MS	15	14	21	24	37	32	:	36	:
- treated outside EU	0	2	0	1	1	1	:	2	:
Reuse	**2**	**4**	**4**	**5**	**6**	**4**	:	5	:
Recycling	**269**	**345**	**426**	**485**	**525**	**512**	:	494	:
Other recovery	37	41	51	51	47	41	:	48	:
Total Recovery	**308**	**390**	**481**	**541**	**579**	**557**	:	**542**	**:**
Collected vs. Put on market	*34%*	*38%*	*56%*	*63%*	*77%*	*86%*	:	*83%*	:
Recycled vs. Collected	*78%*	*77%*	*80%*	*81%*	*81%*	*82%*	:	*81%*	:

IT and telecom equipm. ITT (6 wt% monitor), in kt	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Products put on market	**1514**	**1573**	**1494**	**1478**	**1416**	**1274**	**1225**	**1250**	**1190**
Waste collected	**389**	**569**	**628**	**695**	**677**	**648**	:	**618**	**640**
- waste collected from hh	316	507	564	640	611	582	:	519	502
- waste collected from others	85	81	78	69	81	76	:	99	138
- treated in MS	85	81	78	69	81	76	:	553	577
- treated in another MS	25	30	26	27	31	25	:	33	36
- treated outside EU	1	2	1	1	5	4	:	8	4
Reuse	**12**	**19**	**32**	**35**	**42**	**41**	**14**	**13**	**13**
Recycling	**275**	**407**	**451**	**498**	**463**	**450**	:	**490**	**504**
Other recovery	29	36	40	43	34	39	:	42	38
Total Recovery	**308**	**390**	**481**	**541**	**579**	**557**	**:**	**545**	**555**
Collected vs. Put on market	*26%*	*36%*	*42%*	*47%*	*48%*	*51%*	*:*	*49%*	*54%*
Recycled vs. Collected	*71%*	*72%*	*72%*	*72%*	*68%*	*69%*	*:*	*79%*	*79%*

Assuming, as explained in the main report, in 2014 TV sales were 40 m units at a weight of 12 kg/unit, which amounts to 540 kt (540 million kg). The WEEE statistics for 2014 mention 738 kt of products put on the market in the category of consumer electronics. If this is correct, then the TVs are almost 75% of the total. Likewise, in 2014 10 million computer monitors were sold e.g. with a weight of 7 kg/unit. The resulting 70 kt is 6% of the total ITT product weight put on the market, according to the WEEE statistics.

If we use these multipliers throughout the WEEE statistics, it means that in 2014 there were 610 kt of electronic displays placed on the market. Almost 500 kt (460 kt TV + 37 kt monitor) of display-waste was collected, presumably from displays put on the market 7 to 10 years before. Of this 400 kt (370 kt TV and almost 30 kt monitors) was recycled (80%), for 39 kt there was probably energy recovery from incineration and 4 kt was re-used. So in total 443 kt (89%) was recovered in some useful way and thus the remaining 57 kt was officially discarded, i.e. either incinerated without heat recovery or thrown away as landfill.

Figure 15.1 below gives the estimated TV weight (in kg) and the viewable surface area (in dm2) over the 1990-2030 period. It is estimated by VHK on the basis of several Bills-of-Materials published over the past period and extrapolation of the latest trends into the future.

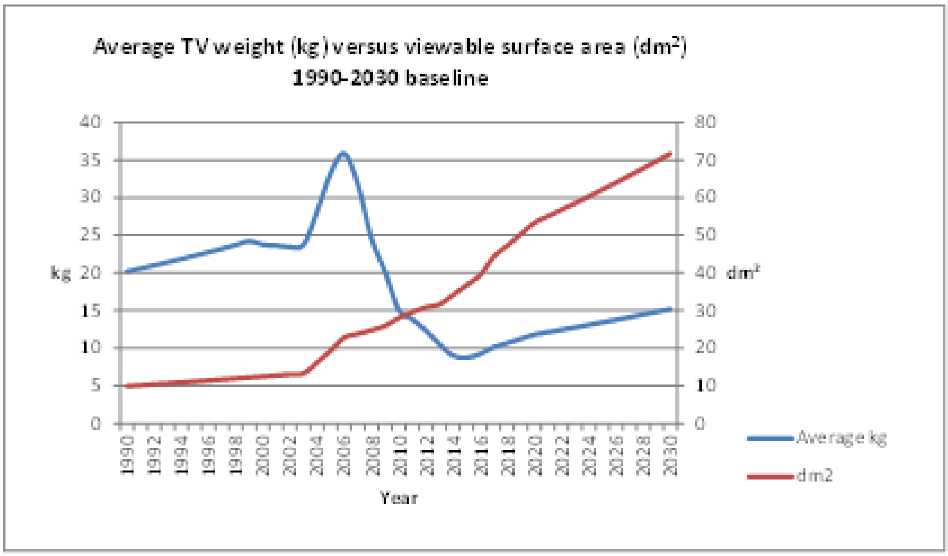

Figure 15.1: Average TV weight (kg) and viewable surface area (dm2) 1990-2010.

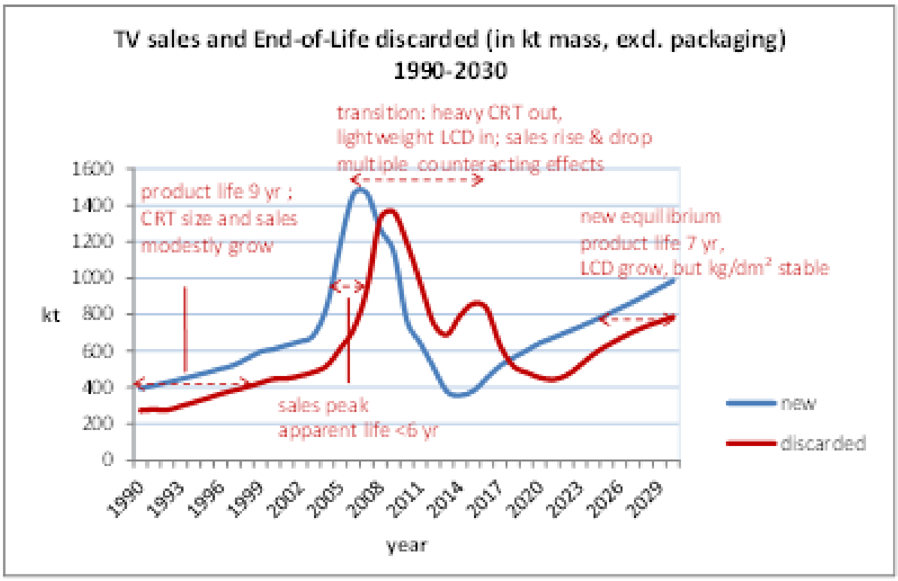

Figure 15.2: Mass flows related to TV sales and End-of-Life 1990-2015 (real) and 2016-2030 (projections)

Figure 15.2 illustrates how the 'light-weighting' of TVs has its impact over time.

Until 15 August 2018 the minimum WEEE targets are a recovery rate of 80% and 70% to be prepared for re-use and recycled. After that date 85% should be recovered and 80% shall be prepared for re-use and recycled. In other words, the non-recovered fraction is a concern.

According to the plastics recyclers, the halogenated flame retardants are the main cause that a part of the plastics cannot be recovered in any useful way, i.e. not even for heat recovery.

2. HALOGENATED FLAME RETARDANTS

Following the EcoReport calculations that VHK made for the Commission in 2012, corrected for more recent sales, appropriate measures in the field of flame retardants could deliver at the most an extra 36 kt bulk-plastics and 40 kt technical plastics from recycling. The EU27 plastics demand in recent years was around 45-50 Mt, so this 76 kt amounts to 0.17%. Note that for individual technical plastics, like ABS (750 kt EU demand, source PlasticsEurope), the ca. 30 kt extra recovered from displays represents about 4%, which is significant.

Legal background

The use of brominated halogenated flame retardants (BFRs) in plastics is regulated through REACH[30], RoHS[31], WEEE[32] and the WFD[33] legislation. REACH regulates Tetrabromobisphenol A (TBBPA), Hexabromocyclododecane (HBCD) and Decabromodiphenyl Ether (Deca-BDE).

- Tetrabromobisphenol A (TBBPA), a flame retardant used in Printed Circuit Boards and ABS plastics and as such used in a compound with no restrictions in use.
- Hexabromocyclododecane (HBCD), a flame retardant used in thermal insulation with a 'sunset date' of 21.8.2015,
- Decabromodiphenyl Ether (Deca-BDE), a flame retardant used in enclosures of Electric and Electronic appliances and in that application restricted in Europe since July 2008.

In the RoHS directive, Polybrominated Biphenyls (PBB), Octa-BDE and Penta-BDE are banned and the use of Deca-BDE is restricted[34]. The ban relates to concentrations above 0.1% in homogenuous materials (0.01% for Cd), but there are exemptions.

Under the Water Framework Directive Octa-BDE & Deca-BDE are listed among the substances to be monitored, while Penta-BDE is the only BFR listed as a hazardous substance.

Following the WEEE Directive, plastic containing brominated flame retardants has to be removed from any separately collected waste of electric and electronic equipment.

BRFs are regulated under the mentioned frameworks, because they are persistent, bioaccumulative and toxic ('PBT') and some are classified as very persistent and very bioacccumulative ('vP/vB').

Why halogenated flame retardants and which types?

[30] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.093.01.0024.01.ENG
[31] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=celex:32011L0065
[32] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32012L0019
[33] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32000L0060
[34] Under the Water Framework Directive Octa-BDE & Deca-BDE are listed among the substances to be monitored, while Penta-BDE is the only BFR listed as a hazardous substance.

BFR and other HFR are used in plastics because they are a low-cost solution to obtain high flame retardancy of UL94 class V1 or higher.
The necessity to use BFR or another halogenated FR is expected to diminish once the so-called ‘external ignition requirement’ is stricken from EU safety regulations. This so-called ‘candle test’ entails an open flame being applied to the back cover of the television over a prolonged period of time without the back cover actually catching fire. It is prescribed in EN 60065:2002/A11:2008, a harmonised standard for the Low Voltage Directive (LVD) compliance. This standard has been superseded by EN 60065: 2014, which will in turn be superseded 20.9.2019 by harmonised standard EN 62386-1:2014 that no longer requires this ‘candle test’.[35]

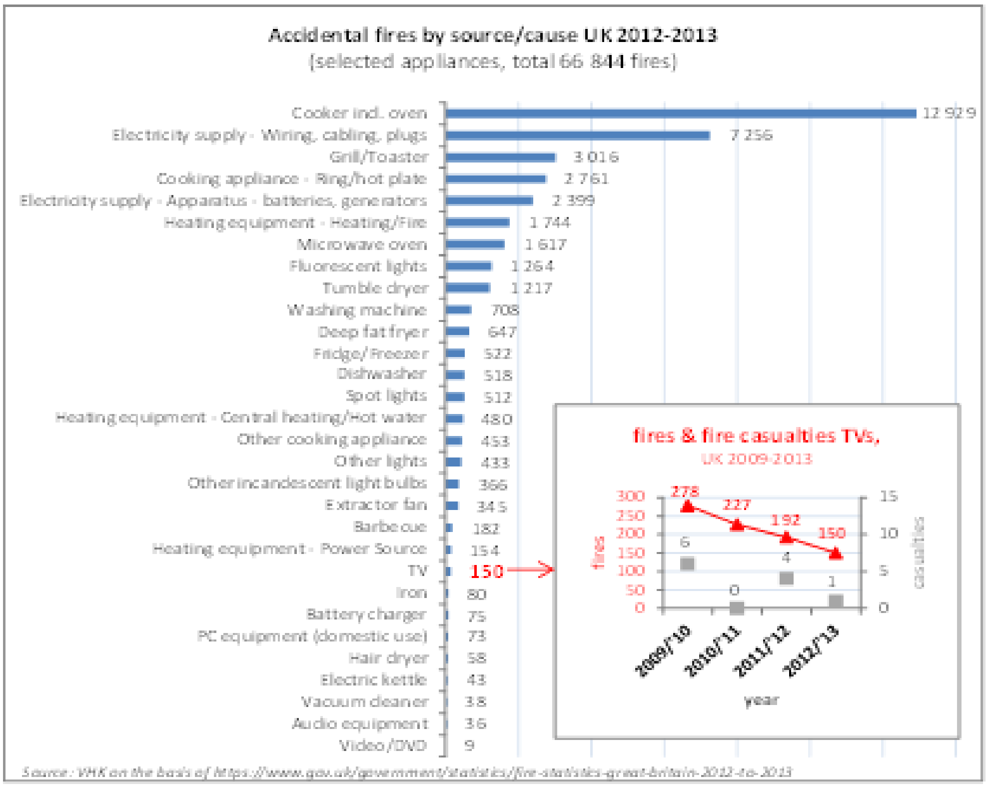

Figure 15.3: Recent UK fire statistics for TVs and other appliances

Green NGOs like ECOS have been fighting the candle test for several years, as it is claimed to be disproportionate, based on fire statistics that are outdated (UK 2001) and relate to a TV technology (CRT TVs) now disappeared from the market.

BFRs are used, apart from TBBPA in printed circuit boards, in the plastic back-cover of televisions. Another group of so-called phosphate flame retardants (PFR), a non-halogenated flame retardant, is used more often in combination with PC/ABS back-covers.

VHK investigated more recent UK fire statistics that seem to confirm the statement from the Green NGOs (figure 15.3).

35 Commission communication in the framework of the implementation of Directive 2014/35/EU of the European Parliament and of the Council on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits (2017/C 298/02), OJ, C298, p. 14, d.d.8.9.2017

Possibilities for recovery

The European Flame Retardant Association (EFRA) analysed the waste stream of 610 LCD TVs and found 17% of plastic back covers containing HIPS (High Impact Polystyrene) with 2 types of Brominated Flame Retardants (BFRs) and 26% containing PC/ABS with PFRs (phosphate FRs). Aged plastics with PFRs/BFRs showed good recyclability and could be successfully reapplied in new back covers[36]. High precision sorting is challenging but trials on separation of plastics with BFRs using e.g. DE-XRT (Dual Energy X-Ray Transmission) and identification/sorting of a black plastics with sliding spark (SSSP[37]) and FTIR[38] hand scanner were satisfactory. As regards miscibility EFRA found that PMMA and ABS in PC/ABS is lowering the physical properties and 2% wt. of contamination of other plastics can already have a substantial negative effect on the physical properties of plastic recyclates. EFRA estimates that only 12% of the plastics in a display are recycled.

The figure 15.4 shows that plastics make up some 40% of the product weight and that 25% of the product weight goes into the enclosure. The back-cover is said to account for 1.6 kg.

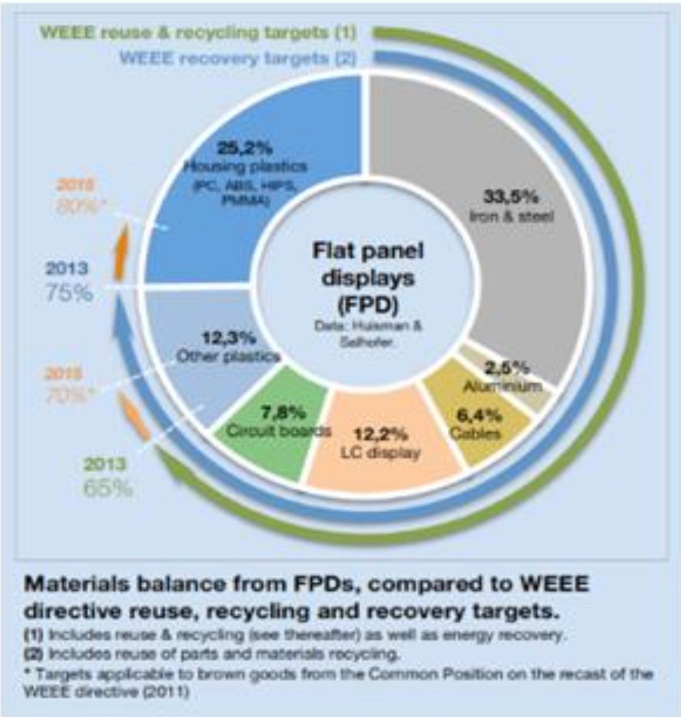

Figure 15.4: Materials balance of flat panel displays, compared to WEEE targets (source: EFRA)

Note that since June 2017, EFRA is no longer a member of the chemical industry council Cefic. A new association called PINFA, representing industries of non-halogenated flame retardants, is now the only CEFIC association dealing with flame retardants[39].

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[36] Recycling of Plastics from LCD Television Sets, Pilot project on mechanical plastics recycling from post-consumer flat panel display-LCDs

[37] http://www.iosys-seidel.de/en/sss3.html

[38] Fourier transform infrared spectroscopy

[39] See www.pinfa.eu

Effects on health

Halogenated flame retardants, also known as organo-halogen flame retardants contain chlorine or bromine bonded to carbon. Halogenated compounds with aromatic rings can degrade into dioxin derivatives, particularly when heated, such as during production, a fire, recycling, or exposure to sun. In addition, when some of the halogenated flame retardants such as pentabromodiphenylether derivatives are metabolized, they form hydroxylated metabolites, even more toxic than the parent compound. These metabolites, for example, may compete strongly to bind with transthyretin or other components of the thyroid system, can be potent oestrogen mimics and can affect neurotransmitter receptor activity. Halogenated flame retardants have been shown to cause cancer, immune and endocrine disruption, and adverse reproductive and neurodevelopmental effects in animals (Birnbaum et al. 2003). In humans, these substances are associated with reproductive abnormalities (Meeker & Stapleton 2009), diabetes (Lim et al. 2008), thyroid dysregulation (Turyk et al. 2008, Meeker et al. 2009), cognitive changes (Roze et al.2009, Herbstman et al. 2010), and undescended testicles in new-born boys (Main et al. 2007).

When products with flame retardants reach the end of their useful life, they are typically recycled, incinerated, or landfilled. Recycling can contaminate workers and communities near recycling plants, as well as new materials, with halogenated flame retardants and their breakdown products. Electronic waste is often melted to recycle metal components, and such heating can generate toxic dioxins and furans. Poor-quality incineration similarly generates and releases high quantities of toxic degradation products (Speight, 2017).

ECOS, one of the environmental NGOs that has been fighting the use of HFRs for many years, reports that studies have found associations between exposure to certain flame retardants and adverse health effects, including cancer, reproductive toxicity, immunotoxicity, neurotoxicity, reduced IQ, birth defects, and hormonal changes. Infants and young children are the most vulnerable group, as they are acutely susceptible to neurodevelopmental toxicants and endocrine disruptors.[40]

Brominated flame retardants also change the physical properties of plastics, resulting in inferior performance in recycled products.

Are there substitutes?

The composition of LCD display back covers is shown in Fig. 15.5. Only the non-FR plastics HIPS and ABS are mechanically recycled from waste streams on an industrial scale (Peeters, 2011). Other FR plastics, such as PC, PC/ABS with P FR, HIPS/PPE with PFR and ABS/PMMA are currently mostly thermally recycled, a relatively expensive process. Many manufacturers have already started using alternative flame retardants, such as metal hydroxides and phosphorus. Separating FR plastics treatment requires several technical challenges, while high waste volumes are required for this treatment to become economically viable due to the high investment costs. However research demonstrated that for example, substitutes based e.g. on PFR PC/ABS plastic recycling is technically feasible with existing technologies and is economically viable in Europe. Moreover, it can be started up at a lower throughput, which requires limited investments (Peeters 2014).

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40 Endocrine disruptors are substances that impact the hormone system. They interfere with the synthesis, secretion, transport, binding, action, or elimination of natural hormones in the body that are responsible for development, behaviour, fertility, and maintenance of homeostasis (normal cell metabolism).and damage in particular during the growth process.

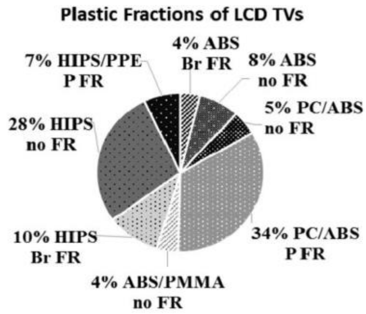

Figure 15.5: Plastic types found LCD displays in 2015 (source Wagner 2017)

3. CRITICAL RAW MATERIALS

The printed circuit boards (PCBs) of electronic displays contain precious, rare and critical raw materials. For this reason it is standard practice to dismount the PCBs from the rest of the display and feed it into a different route. This route can be a dedicated shredder followed by chemical-physical processes to separate the valuable fractions. On some occasions, the electronics on the PCBs can also be further disassembled and sorted for optimised recovery.

In any case, it is important that the PCBs are treated differently and do not go in the same shredder as the rest of the displays. According to JRC-IES, this will increase the recovery rate of silver (Ag) from the current 16% to 32%, gold (Au) from 14% to 29%, platinum (Pt) and Palladium (Pd) from 15% to 30%.

Table 15.6: Extra recovery of critical raw materials in el.displays due separate treatment

Metal	Content per LCD display[1]	Content in 77 mn units sold in EU in 2012	Recovered today [2]		Recovery after proposed measures [2]		Extra material recovered per year (at 77 m units)
	mg	kg	%	kg	%	kg	kg
Silver	580	44 660	16%	7 146	32%	14291	7 146
Gold	140	10 780	14%	1 509	29%	3126	1 617
Palladium	44	3 388	15%	508	30%	1016	508

[1] Buchert, M. et al., Recycling critical raw materials from waste electronic equipment, Öko-Institut, 2012.
[2] Source: JRC-IES for DG ENV.

For comparison:

In 2011 global silver fabrication demand was around 15000 t, of which around half came from the electronics industry. Europe represents around 17.7% of global silver fabrication demand, i.e. around 2700 t, hence, the 7 t extra recovery from displays represents 0.25% of Europe's total and 0.5% of Europe's silver demand by the electronics industry (source: www.SilverInstitute.org, 2012).

Over the period 2008-2012 the global gold demand was reportedly 4147 t, of which 10.8% came from the electronics industry (439 t). Assuming that Europe represents around 18-20%

of global gold demand, this comes down to around 750 t in total and 80 t in the electronics industry, respectively. Hence, the 1.6 t extra recovery from displays represents 0.2% of Europe's total demand and 2% of Europe's gold demand by the electronics industry (source: www.gold.org, 2012). Likewise, the 2012 global mine production of Palladium was 200 t (source USGS, 2013). If Europe accounts for 18% of global demand (36 t) then the extra 0.5 t amounts to 1.4%.

LCD screen

Indium (In) is the main critical raw material in the screen. It is used, in the form of Indium-Tin-Oxide (ITO) for its transparency and electric conductivity. Indium is used also in other applications like solar panels, etc., but 60-75% (depending on the source) ends up in flat panel displays.

Indium is not particularly rare or (eco)toxic nor is there an import reliance (see figure below), but it is on the EU Critical Raw Materials[41] list because it is considered difficult to substitute –especially in flat panel displays. The End-of-Life recycling input rate is 0% for flat panel displays, mainly because the quantities of ITO per flat panel display are low[42]. Layer thickness is around 200 nm and thus a typical TV yields between 1 and 1.5 g ITO. This makes the costs of recycling prohibitive. Several researchers are looking to increase the concentration of ITO in the waste product, e.g. by chemical leaching (using HCl) or bioleaching (using bacteria) of the ground glass cullets/ITO mix. This is promising but has not (yet) led to commercial implementation. More details on indium processing can be found in literature[43].

Disassembly of the glass panel from a TV is not critical, it is typically clamped between bevel and back-cover. Once the backcover is removed (6-8 screws typically and additional form-locks), the glass panel with filters etc. can be removed. There is no welding, soldering or gluing.

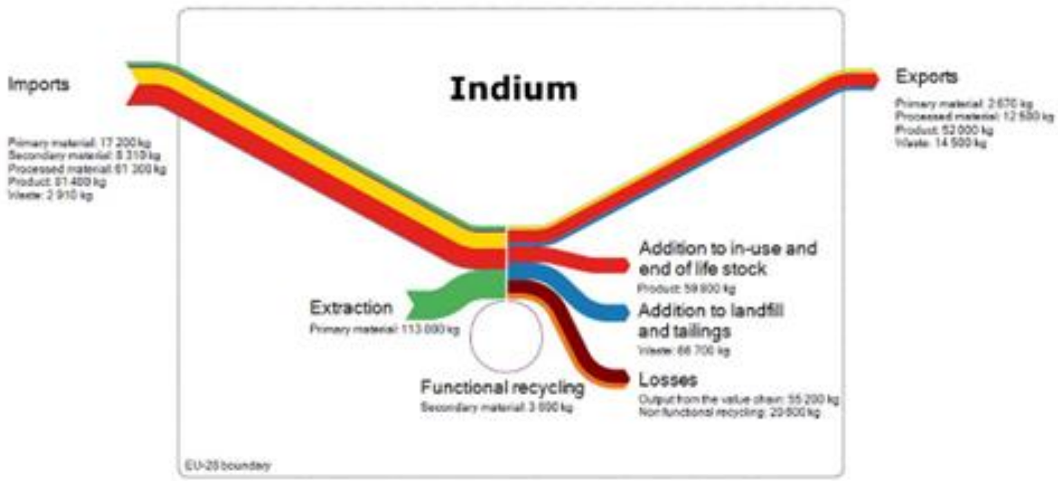

Figure 15.6: Indium material flows EU-28 (source: MSA-group in EC 201889)

[41] COM/2017/0490 final

[42] Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions on the 2017 list of Critical Raw Materials for the EU, Brussels, 13.9.2017 , COM(2017) 490 final

[43] Martin Lokanc et al., The Availability of Indium: The Present, Medium Term, and Long Term, NREL for US DoE, October 2015.

4. DISASSEMBLY/DISMANTLING

The following example is to illustrate the recycling of a modern flat panel display.

Disassembly of an LED LCD TV is relatively straightforward: The back cover is attached either by 6-8 screws (for TVs) and/or through a click/clamp joint with the front-cover (typical for monitors). Inside there are 2-3 printed circuit boards, for power supply (if there is no external power supply as with most monitors and some TVs), signal processing and timing control. The inverter board, necessary for CCFL backlights, will be no longer part of future electronic displays. This also means that there will be no high-voltage part inside the display.

The PCBs for power supply, signal processing and timing control are screwed to the metal chassis of the LCD module, sometimes with a separate metal cover. In most PC monitors and in some TVs the power supply, a part with high copper (transformer) and palladium (capacitors) content, is external. This means it is easy to repair/replace and to recycle.

After removing the front bevel (click/clamp), the TFT LCD panel and all the optics (filters and possibly PMMA sheet) can be dismounted.

The LCD-module is usually a simple stack (no screws, no glue) of direct or side backlight, optical films & diffusers (e.g. 5-7 mm PMMA-sheet) and finally the LC glass-sheets with a flatcable to driver-ICs. The stack is encased in a metal sheet chassis, designed for mechanical rigidity/strength, heat dissipation and connection to PCBs, cabinet covers and stand.

Most ‘tear-down’ video demonstrations show that a disassembly time of 4 minutes is realistic, i.e. the time it takes to unscrew 15-20 screws, wiggle a knife between front- and backbezel, cut some cables and sort the pieces. JRC-IES (2013) found that for the current waste stream of televisions and monitors, i.e. including CCFLs, half of the smaller models (<25”) were dismantled in 260 seconds and half of the larger models (>25”) were dismantled in 480 seconds in EU recycling facilities.

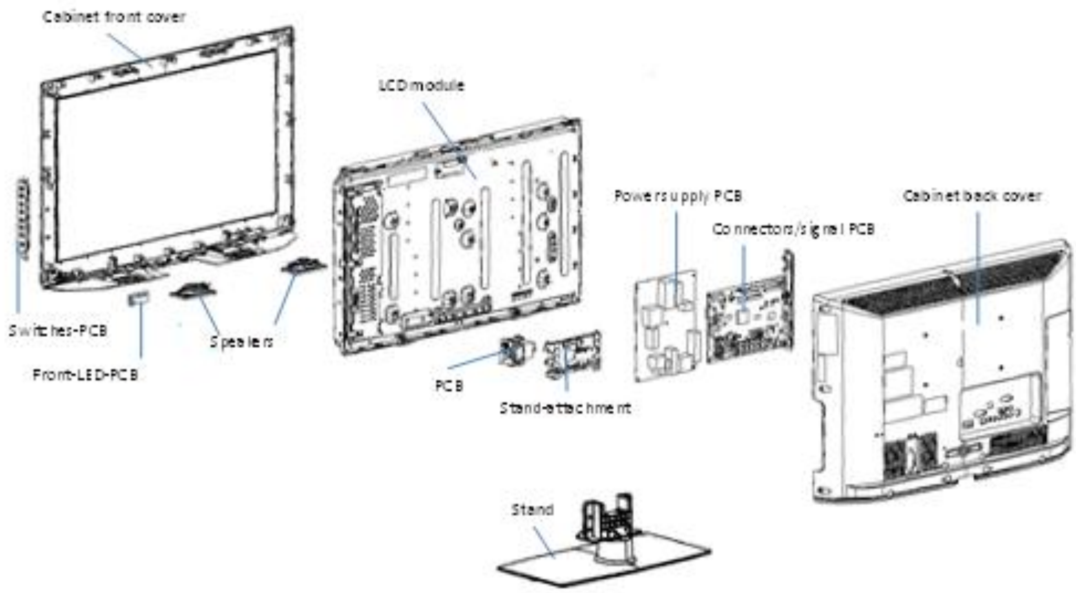

Figure 15.7: Exploded view of LCD TV with main components (example)

Outside the above disassembly technique, it is believed that the miscibility of plastics does not create any particular problems in recovery of materials. The figure 15.8 below gives the miscibility of plastics in recycling.

	ABS	ABS BFR	HIPS	HIPS BFR	PET	PC	PMMA	PC/ABS PFR	HIPS/PPE PFR
ABS	G								
ABS BFR	G	G							
HIPS	Y	Y	G						
HIPS BFR	Y	Y	G	G					
PET	O	O	O	O	G				
PC	G	G	O	O	G	G			
PMMA	O	O	O	O	Y	O	G		
PC/ABS PFR	G	R	O	R	R	G	O	G	
HIPS/PPE PFR	O	O	G	G	R	O	O	Y	G

G	Good miscibility (contamination>5%, properties>80%)
Y	Resonabile miscibility (contamination=2-5%, properties>80%)
O	Limited miscibility (contamination=0.1-2%, properties>80%)
R	Bad miscibility (contamination<0.1%, properties<80%)

Figure 15.8: Miscibility of plastics in recycling (source EFRA 2014)

According to the WEEE Directive, plastic parts with brominated flame retardants need to be removed separately (as do TFT panels and PCBs). Also for other halogenated flame retardants (Chlorinated, fluorinated) this is good practice.

5. PRODUCTION PHASE: NF3 EMISSIONS

The emission of the high-GWP NF3 in display-panel production is mentioned here to be complete, not because it is an issue that the EU can easily address as the emission does not take place on EU soil.

Historically, the manufacturing process of LCD panels had a specific negative environmental impact ('GWP') because of the used cleaning agents, such as SF_6 and perfluoroethane. Over the last few years most manufacturers, however, have replaced traditional cleaning agents by NF_3, which was considered to have lower environmental impact. NF_3 has a high GWP-100 of 17 200 CO_2 eq. but its effect on the Earth’s atmosphere was assumed small.

As NF_3 became a popular cleaning agent[44] and because approximately 2% of its input is released into the atmosphere during production, the NF_3 concentration in the atmosphere has grown rapidly and it has recently been included in the upcoming UNFCCC 2nd Kyoto protocol.[45]

In 2010, the total global production of NF_3 amounted to 8000 t, of which at least around 6000 t was used as a cleaning agent in display panel manufacturing[46]. If this was exclusively used in the worldwide production of the large TFT panels remaining in the scope of the measures, the cleaning operation of the average panel would require 24 g[47] of NF_3 and, 2% of that, i.e. 0.48 g would be released into the atmosphere. The GWP impact of 0.48 g of NF_3 amounts to 8.8 kg CO_2 equivalent. According to the EcoReport analysis, the GWP impact of other production operations and materials amounts to 274 kg CO_2 equivalent. The total NF_3 emissions caused by the 77 million electronic displays bought annually to the EU27 amount to approximately 0.7 Mt.

[44] Global production 2010 estimated at 8000 t. (wikipedia)

[45] Rivers, A., Nitrogen trifluoride: the new mandatory Kyoto Protocol greenhouse gas, Ecometrica, August 15, 2012. http://ecometrica.com/blog/nitrogen-trifluoride-the-7th-mandatory-kyoto-protocol-greenhouse-gas

[46] Hard data are not available. Most sources mention that ‘most’ is used in display manufacturing. The figure of 6000 t comes from wikipedia.en

[47] 6000 t divided by 250 million large TFT panels produced worldwide.

Annex 16: Acronyms & conversion table

3D	Three dimensional
4K	4000 pixels in horizontal dimension (a high resolution digital video format)
A	Screen surface
ABC	Automatic Brightness Control
AIO	All in one
AMOLED	Active-Matrix Organic Light-Emitting Diode
AP	Acidification Potential
APD	Auto Power Down
APL	Average Picture Level
AT	Austria
BAT	Best available technology
BE	Belgium
BEF	Brightness Enhancement Film
BLU	Backlight unit
Bln or bn	Billion (1 bn= 10^9)
BNAT	Best Not yet Available Technology
CCFL	Cold-cathode fluorescent lamp
cd	Candela
CENELEC	European Committee for Electrotechnical Standardization
CF	Consultation Forum established under Ecodesign Directive, Art. 18
CH	Czech Republic
CN	China
CRT	Cathode-ray tube
CSTB	Complex Set-top Boxes
DBEF	Dual brightness enhancement film
DDI	Display driver integrated
DDIC	Display Driver Integrated Circuit
DE	Germany
DK	Denmark
DOE	US Department of Energy
DPF	Digital photo frames
DVI	Digital Visual Interface
e-beam	Electron-beam
EC	European Commission
ECOS	European Environmental Citizens Organisation
EEA	European Economic Area, European Environmental Agency
EED	Energy Efficiency Directive
EEI	Energy Efficiency Index
EMI	Electro-magnetic interference
EN	European Norm
ENTR	Directorate-General for Enterprise and Industry (European Commission)
EPA	Environmental Protection Agency
EPBD	Energy Performance of Buildings Directive
EP	Eutrophication Potential, European Parliament
ErP	Energy related Product
ES	Spain
ETS	Emissions Trading Scheme
EU	European Union
EUV	Extreme ultra-violet
FPD	Flat panel display
FR	France
GPP	Green Public Procurement
GWP	Global Warming Potential

HD	High definition
HDMI	High-Definition Multimedia Interface
HDR	High Dynamic Range
HU	Hungary
IA	Impact assessment
IEC	International Electrotechnical Commission
IEEE	Institute for Electrical and Electronics Engineers
IGZO	Indium Gallium Zinc Oxide
Inch	unit of length, 1 inch= 1" = 2.54 cm
IT	Information technology
ITO	Indium tin oxide
JRC	European Commission Joint Research Centre
JRC-IES	JRC -Institute for Environment and Sustainability (Ispra, Italy)
JRC-IPTS	JRC- Institute for Prospective Technology Studies (Sevilla, Spain)
kWh	kilowatt-hour
LCD	Liquid Cristal Display
LED	Light-emitting diode
LGP	Light Guide Plate
lm	Lumen
MEErP	Methodology for the Ecodesign of Energy-related Products
MEEuP	Methodology for the Ecodesign of Energy-using Products
MEPS	Minimum Energy Performance Standards
MF	Multi-functional
MOCVD	Metal Organic Chemical Vapour Deposition
Mp	Megapixels
msp	Manufacturer selling price
NGO	Non-governmental organisation
NL	the Netherlands
NMS	New Member States
OEM	Original equipment manufacturer
OJ	Official Journal of the European Union
OLED	Organic light emitting diode
P	Electric power consumption
PAH	Polycyclic Aromatic Hydrocarbons
PC	Personal computer
	Polycarbonate
PCB	Printed Circuit Board
PDP	Plasma Display Panel
PECVD	Plasma Enhanced Chemical Vapour Deposition
PET	PolyEthylene erephthalate
PM	Particulate Matter (with addition of size PM5, PM10, etc.)
PMMA	Polymethyl methacrylate
PO	Power On-mode
POP	Persistent organic pollutants
R&D	Research & development
SME	Small or Medium Enterprise
TEC	Treaty on the European Communities
TFEU	Treaty on the Functioning of the European Union
TFT	Thin film transistor
TV	Television
USB	Universal Serial Bus
UV	Ultraviolet
VAT	Value added tax
VOC	Volatile Organic Compounds
W	Watt

Units used in this report

CO_2 eq.	Carbon dioxide equivalent, unit for Greenhouse Gas Emissions (usually over 100 years)
g	gramme, ISO-unit of mass
h	hour, also used as 'height' denominator
m, m^2, m^3	meter, square meter, cubic meter; SI-units of length, surface, volume
W	Watt, unit of power
Wh, kWh	Watt hour, unit of energy (1kWh = 1 000Wh = 3.6 MJ)
cd	Candela; SI base unit of luminous intensity
inch	Unit of length in a number of systems of measurement (1 inch = 2.54 cm)
Mp	Megapixels; physical point in a raster image (1Mp = 1 mln pixels)

Chemical names used in this report

a-Si	amorphous Silicium
Ag	Silver
Au	Aurum (gold)
CO_2	Carbon dioxide
In	Indium
Li-Ion	Lithium ions
NF_3	Nitrogen tri-fluoride
SF_6	Sulphur hexa-fluoride
Pd	Palladium
Pt	Platinum
Si	Silicium
SiH_4	Silane
SiN	Silicon nitrides

Display panel conversion diagonal in inch to surface area in square dm (only for size ratio 16:9)

Inch	dm²	Inch	dm²	Inch	dm²	Inch	dm²
1	0.03	**15**	6.20	**31**	26.49	**47**	60.90
2	0.11	**16**	7.06	**32**	28.23	**48**	63.52
3	0.25	**17**	7.97	**33**	30.02	**49**	66.20
4	0.44	**18**	8.93	**34**	31.87	**50**	68.93
5	0.69	**19**	9.95	**35**	33.77	**51**	71.71
6	0.99	**20**	11.03	**36**	35.73	**52**	74.55
7	1.35	**21**	12.16	**37**	37.74	**53**	77.44
8	1.76	**22**	13.34	**38**	39.81	**54**	80.39
9	2.23	**23**	14.58	**39**	41.93	**55**	83.40
10	2.76	**24**	15.88	**40**	44.11	**56**	86.46
11	3.34	**25**	17.23	**41**	46.35	**57**	89.57
12	3.97	**26**	18.64	**42**	48.63	**58**	92.75
13	4.66	**27**	20.10	**43**	50.98	**59**	95.97
14	5.40	**28**	21.61	**44**	53.38	**60**	99.25
		29	23.19	**45**	55.83		
		30	24.81	**46**	58.34		

Note: 1 inch= 0.254 dm; 1 square dm = 15.5 square inch.

Annex 17: References

Adel Bastawros, Jian Zhou, Michael J. Davis, ZheChen, and Wibowo Harsono, *Diffuser Films and Optical Performance in LCDs,* Information Display Materials issue Vol.28 no.1, January 2012

AEA Group, *EuP Group Analysis (I), Lot 3: Sound and Imaging Equipment Restricted Task 1 - 3 Final Report (DPFs),* January 2010

Agam Shah, *Acer Cuts Staff in Europe, Takes $150 Million Charge*, June 1, 2011

AIXTRON SE, *IR Master Presentation – Q3/2012*, 2012

AIXTRON SE, *Small details - infinite options*, 2011

Alex Wolfgram, *Archos unveils multi-touch Android TV*, January 4, 2013

Alex Wolfgram, *Sharp sees shortage of 5-inch Full HD panels on Aquos Phone sales; to release new IGZO smartphone in 2013*, January 3, 2013

Andrew Rassweiler, *Low-End Apple iPad mini Carries $188 Bill of Materials*, November 16, 2012

Anna Karin Jönbrink (IVF Industrial Research and Development Corporation), preparatory study *"Personal Computers (desktops and laptops) and Computer Monitors*, Report for Tender No. TREN/D1/40-2005/LOT3/S07.56313Apple Inc, *27-inch LED Cinema Display, Environmental Report*, 2010

Ardente, F., Mathieux, F. *Part 1 - Guidance on Reusability / Recyclability / Recoverability; Recycled content; use of priority resources; use of hazardous substances.* European Commission. Joint Research Centre. Institute for Environment and Sustainability. Report n. 2 of project "Integration of resource efficiency and waste management criteria in European product policies – Second phase". July 2012 (draft).

Ardente F., Mathieux F., Talens Peiró L., Revision of methods to assess material efficiency of energy related products and potential requirements - Environmental Footprint and Material Efficiency Support for Product Policy, December 2016,Ardente, F., Mathieux, F. *Application of the project's methods to three product groups*. European Commission. Joint Research Centre. Institute for Environment and Sustainability. Report n. 2 of project "Integration of resource efficiency and waste management criteria in European product policies – Second phase". November 2012.

Mathieux F., Ardente g. et al, *Critical raw materials and the circular economy, Background report*, December 2017, ISBN 978-92-79-74283-5

Recchioni M., Ardente F., Mathieux F. , Environmental footprint and material efficiency support for product policy - Feasibility study for a standardized method to measure the time of extraction of certain parts from an electrical and electronic equipment - Study, March 2016, ISBN 978-92-79-33276-0

Ardjuna Seghers, *Sony, Toshiba And Hitachi Merge Into Japan Display*, April 3, 2012

AUO, *Experience Sharing of Carbon Footprint of LCD TV*, January 19, 2010

AUO, *TFT-LCD process* URL: http://auo.com/?sn=189&lang=en-US

Avdeals America, *Fabricating Colour TFT LCD Displays* URL: http://www.plasma.com/classroom/fabricating_tft_lcd.htm

Birnbaum, Linda & F Staskal, Daniele. (2004). Brominated Flame Retardants: Cause for Concern?. Environmental health perspectives. 112. 9-17. 10.1289/ehp.6559.

Blaupunkt AudioVision GmbH & Co. KG, *Blaupunkt celebrates move into new plant,* Penang (Malaysia) / Hildesheim (Germany), July 2012

Carolyn Mathas, *CCFL and LED price gap closes as CCFL costs explode*, August 13, 2012

Centerdata, Study assessing consumer understanding of a draft energy label for electronic displays - Final report, 15/09/2017

Centre for Strategy & Evaluation Services CSES, *Evaluation of the Ecodesign Directive (2009/125/EC)*, Final Report, March 2012. available at http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/review/files/ecodesign_evaluation_report_part1_en.pdf

Chunghwa Picture Tubes Ltd. (CPT), Company data URL: http://www.cptt.com.tw/index.php?option=com_content&task=view&id=13&Itemid=32

Chunghwa Picture Tubes, Ltd., *Corporate Social Responsibility Report*, 2011

Clark Tseng, Dan Tracy, *LED Fab Investments: Capacity Expansion Cools Slightly*, April 3, 2012

CLASP, ECOS, EEB, TopTen, (2015), CLOSING THE 'REALITY GAP' - ENSURING A FAIR ENERGY LABEL FOR CONSUMERS, available from https://clasp.ngo/publications/closing-the-reality-gap-ensuring-a-fair-energy-label-for-consumers, Öko-Institut e.V; Eunomia Research & Consulting Ltd (2015).

Study for the review of the list of restricted substances under RoHS 2, Analysis of impacts from a possible restriction of several new substances under RoHS 2 : final version – Study, available at https://data.europa.eu/euodp/data/dataset/study-for-the-review-of-the-list-of-restricted-substances-under-rohs-2-analysis-of-impacts

COM (2011)21 final. *A resource-efficient Europe – Flagship initiative under the Europe 2020 strategy*, Brussels, 26.1.2011.

COM(2011)109 final, *Energy Efficiency Plan 2011*, EC, 8.3.2011.

Commission Decision of 12 March 2009 establishing the revised ecological criteria for the award of the Community Eco-label to televisions (notified under document number C (2009) 1830) (Text with EEA relevance) (2009/300/EC). OJ L 80, 28.3.2009, p. 3

Commission Regulation (EC) No 642/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for televisions (Text with EEA relevance). OJ L 191 , 23.07.2009, p. 42

Commission Decision of 26 October 2009 determining the Community position for a decision of the management entities under the Agreement between the Government of the United States of America and the European Community on the coordination of energy-efficiency labelling programmes for office equipment on the revision of the computer monitor specifications in Annex C, part II, to the Agreement (Text with EEA relevance) (2009/789/EC). OJ L 282, 29.10.2009, p.23

Commission Delegated Regulation (EU) No 1062/2010 of 28 September 2010 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of televisions (Text with EEA relevance). OJ L314, 30.11.2010, p.64

Commission Decision of 9 June 2011 on establishing the ecological criteria for the award of the EU Ecolabel for personal computers (notified under document C(2011) 3737) (Text with EEA relevance) (2011/337/EU). OJ L 151, 10.6.2011, p. 5

Cordeiro F. , Verbist I., Robouch P., Linsinger T., de la Calle M.B. (2011), IMEP-26: Determination of brominated flame retardants in plastic Interlaboratory Comparison Report, Joint Research Centre, Institute for Reference Materials and Measurements, ISBN 978-92-79-20657-3Daewoo Securities Co., Ltd.("Daewoo"), *1Q Review*, May 7,2012

Dainippon Screen Group, *Annual Report 2011*, 2011

David Hsieh (Display Search), *LCD Demand, Panels, Substrates All Move From Large to Larger*, 2006

David Lussey, *Quantum-Tunnelling-Composite Touch-Screen Technology*, Information Display Materials issue Vol.28 no.1, January 2012

DG Environment and the Joint Research Centre, "Integration of resource efficiency and waste management criteria in European product policies - Second phase", July 17, 2012

Digitimes, *China smart device market sees massive growth in 2012*, November 28, 2012

Digitimes, *Global display market worth US$164 billion by 2017, says Markets and Markets*, December 12, 2012

Digitimes, *Taiwan panel makers squeezed by in-cell and low-cost touch solutions*, September 27, 2012

Digitimes, *2013 TFT LCD industry and market outlook*, December 12, 2012

Digitimes, *China LED competitiveness from rare earth packaging and end products*, December 21, 2012

Digitimes, *Connected TV development favorable to China's triple network convergence*, January 30, 2012

Digitimes, *CSOT's quick rise to become China's top LCD TV panel supplier*, November 9, 2012

Digitimes, *Global AMOLED panel capacity soaring*, June 27, 2012

Digitimes, *Korea leads in overall LED competitiveness*, October 17, 2012

Digitimes, *LCD TV market trends and outsourcing strategies for 2013*, January 3, 2013

Digitimes, *LED TV penetration rate expected to reach as high as 90% in 2013*, December 22, 2012

Digitimes, *MOLED panel market forecast 2012-2014*, June 4, 2012

Digitimes, *OLED lighting efficiacy to reach 100 lm/W by 2015*, May 24, 2012

Digitimes, *Smart TV can do it all for home networking,* November 30, 2012

Digitimes, *Tianma successfully produces Full HD and OLED panels during trial production period*, December 3, 2012

Digitimes, *Trends and forecasts in the OLED lighting market, 2010-2020*, May 17, 2012

Digitimes, *Trends in China's LED chip and packaging sector*, December 18, 2012

Digitimes, *Trends in the high- brightness LED lighting market,* February 16, 2012

Digitimes, *User interface technologies fight for smart TV control*, November 2, 2012

Displays Research Technology, *LCD industry poised for recovery as forecast tops $85 billion*, September 5, 2012

Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast). OJ L 285, 31.10.2009, pp. 10-35. This is a recast of 2005/32/EC on ecodesign requirements for energy-using products

Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products (recast). OJ L 153, 10.6.2009, pp. 1-12. This is a recast of Framework Directive 92/75/EC on energy labeling of household appliances (OJ L 297, 13.10.1992, p. 16-19)

Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (OJ 25.10.2003, L 275, p.32-46) with amendments.

Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (EPBD recast), OJ L 153, 18.6.2010, p. 13-35.

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC (EED), OJ L 315, 14.11.2012, p. 1-56.

Dylan McGrath, *Analyst: ASML holds all the cards in litho*, January 4,2012

EE Herald, *South Korea dominates while Chinese suppliers glow inlarge-sized LCD panel market in Q1, reports IHS*, June 7, 2012

EFRA , Recycling of Plastics from LCD Television Sets Pilot project on mechanical plastics recycling from post-consumer flat panel display-LCDs. European Flame Retardants Association, (2014). shttp://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Substance_Review/Substance_Profiles/20140404__Antimony_EFRA_2013.pdf

EMPA, *Swiss Federal laboratories for materials science and technology, Swico Recycling, Disposal of Flat Panel Display Monitors in Switzerland Final Report*, March 2011

EN IEC 62087:2012, Methods of measurement for the power consumption of audio, video and related equipment, April 2012 (ed. 3), (IEC 62087:2011)

EU Energy Star database, *Monitor section, extract Dec. 2014*. www.eu-energystar.org

European Council, Presidency conclusions, March 2007

Foxconn Technology Group, *2011 CSER Annual report*, June 2012

Fraunhofer IZM and Bio Intelligence Services, *Ecodesign Preparatory Study on Complex Set-Top Boxes (Lot 18)*, prepared for the European Commission, 2008.

Fraunhofer IZM and Bio Intelligence Services, *Ecodesign Preparatory Study on Networked Standby (Lot 26)*, prepared for the European Commission, 2011.

Geoff Nairn, *TCL shuts up TV shop in Europe*, 2006

Glass Global, *SCHOTT Fires Up New Melting Tank for TFT-LCD*, 2013

Global Lighting Technologies Inc., Company data URL: http://www.glthome.com/1-2_Locations.html

Global sources electric components, Makers expand TFT-LCD, LED backlight optical film production, January 14, 2013

Harrison, R., Database EU TVs, Feb. 2013, Intertek for the European Commission.

Herbstman Julie et al, 2010. Prenatal Exposure to PBDEs and Neurodevelopment. Environ Health Perspect. 2010 May; 118(5): 712–719.

IEC/TR 62635:2012, *End of life recyclability calculation for electrical and electronic equipment*, Oct. 2012.

Jamie Yap, Malaysia to be Samsung's largest overseas base by 2015, November 23, 2012

Jana Sehnalkova, *The Relations between the Czech Republic and the PRC: Some Key Issues*, September 2010

Jeff Perkins, *LED Manufacturing Technologies & Costs DOE Workshop*, April 2009

Jeffrey Wu, *Chunghwa Picture to be Taiwan's top maker of small and medium panels*, December 29, 2011

Jeffrey Wu, *Troubled Japanese OEMs Drive Outsourced LCD TVs Against In-House Production*, September 10, 2012

Julian Ho, *AUO expected to decrease 32-inch TV panel production by 25% in 1Q13, Taipei*, January 3, 2013

Ken Werner, *Taiwanese CCFL Giant Turns to LED BLU's*, May 19, 2006

Kennecott Utah Copper, *Gold Environmental Profile, Life Cycle Assessment*, 2006

Kevin Parrish, *Sharp Intros IGZO 32-inch 4K2K (3840 x 2160) Display*, November 28, 2012

Knut Sander, Stephanie Schilling, Frank Marscheider-Weidemann, Henning Wilts, Nadia von Gries, Julia Hobohm, *Abfallwirtschaftliche Produktverantwortung unter Ressourcenschutzaspekten, im aufrag des umweltbundusamtes*, August 2012

Kwang-Ryul Kim, Junsin Yi, Sung-Hak Cho, Nam-Hyun Kang, Myung-Woo Cho, Bo-Sung Shin, Byoungdeog Choi, *SLM-based maskless lithography for TFT-LCD*, Applied Surface Science 255 (2009) 7835–7840

LEDinside, *LED Package Price For Lighting Application Falls By 10%, New Developments on LED Backlight Market with Arrival of Direct-Lit Displays*, June 22, 2012

LEDinside, *The Price of LED For Backlight Application Downtrend Curbs in 3Q12, Inventory Adjustment Remains an Issue*, August 7, 2012

LEDs Magazine, *LED market grew by 93% in 2010, driven by backlights*, February 23, 2011

Lim Ji-Sum et al. Association of Brominated Flame Retardants with Diabetes and Metabolic syndrome in the United States Population: 2003-2004. Diabetes Care 2008 Jun;

Loewe, *Investor relations*, December 2012

Logic technologies, Company data URL: http://www.logictechno.com/index.php?option=com_content&view=article&id=2&menuid=69

Lumitronics, Company data URL: http://www.leds.de/en/LED-strips-modules-oxid-oxid-oxid-oxid-oxid/LED-matrix/BacklightMatrix-290x203-70-Nichia-LEDs.html

Main KM, Kiviranta H, Virtanen HE, Sundqvist E, Tuomisto JT, Tuomisto J, Vartiainen T, Skakkebaek NE, Toppari J. Flame retardants in placenta and breast milk and cryptorchidism in newborn boys. Environ Health

Perspect 2007, in press, doi: 10.1289/ehp.9924.

Matthias Buchert, Andreas Manhart, Daniel Bleher, Detlef Pingel, *Recycling critical raw materials from waste electronic equipment*, February 24, 2012

Mathieux Fabrice , Ardente Fulvio et al. (2017), Critical raw materials and the circular economy, Background report - Study, Joint Research Centre (European Commission), ISBN 978-92-79-74282-8

Mathieux F., Ardente F. Talens Peiró L. (2016), Revision of methods to assess material efficiency of energy related products and potential requirements - Environmental footprint and material efficiency support for product policy, Joint Research Centre (European Commission), ISBN 978-92-79-63889-3

Medion, Annual report 2012, short fiscal year January 1, 2012 to March 31, 2012

Meeker, J. D., & Stapleton, H. M. (2009). House Dust Concentrations of Organophosphate Flame Retardants in Relation to Hormone Levels and Semen Quality Parameters. Environmental Health Perspectives, 118(3), 318–323. http://doi.org/10.1289/ehp.0901332

Meskers, C.E.M., Hagelüken, C., Salhofer, S., Spitzbart, M. *Impact of pre-processing routes on precious metal recovery from PCs*. Proceedings of European Metallurgical Conference EMC 2009. Innsbruck, Austria . 28 June – 1 July 2009.

Michael Spaid, *Wet-Processable Transparent Conductive Materials*, Information Display Materials issue Vol. 28 no.1 , January 2012

Michel Anette, Attali Sophie, Bush Eric (2014), European TV market 2007 – 2013 Energy efficiency before and during the implementation of the Ecodesign and Energy Labelling regulations Second report, complemented with 2013 sales data. Topten International Services, Zurich, Switzerland 21th July 2014

Mike King, *LCD backlight market in decline during 2012 due to insufficient demand for LCD TVs*, September 21, 2012

Mike Wheatley, *Plasma Market Share Hits 15-Month Low As LCD TVs Dominate*, August 13, 2012

N. Duque Ciceri, T. G. Gutowski, M. Garetti, *A Tool to Estimate Materials and Manufacturing Energy for a Product*, ...

Nanjing Jright Illuminating, *CCFL for LCD Backlighting*, 2012

Ningsun Zhou S et al.(2010), Liquid chromatography–atmospheric pressure photoionization tandem mass spectrometry for analysis of 36 halogenated flame retardants in fish, Journal of Chromatography A, Volume 1217, Issue 5, 29 January 2010, Pages 633-641

NPD DisplaySearch ,*Updated All-in-One PC Forecast Mirrors Mini-Note Growth, with 13% CAGR from 2010-2015*, April 26, 2010

NPD DisplaySearch, *4K LCD TVs Expected to Outpace OLED TV Shipments*, January 4, 2013

NPD DisplaySearch, *DisplaySearch Forecasts 11% Demand and 13% Capacity Increases for TFT LCD Glass Substrates in 2011*, January 18, 2009

NPD DisplaySearch, *Large-Area Backlight Unit Optical Film Area Demand Grows 22% Q/Q in Q2'09; LG Electronics and 3M Led in Prism Sheet Shipments*, July 7, 2009

NPD DisplaySearch, *Low-Cost Direct LED Backlights to Reduce Premium for LED-Backlit LCD TVs*, January 18, 2012

NPD DisplaySearch, *New AMOLED TV Costs Ten Times More than LCD TV to Produce*, August 8, 2012

NPD DisplaySearch, *OLED Display Technology Moving to Compete in the TV Market*, January 6, 2012

NPD DisplaySearch, *Shipments of Devices with Cover Glass to Increase Threefold in 2011*, December 1, 2011

NPD DisplaySearch, *Summary of The TFT LCD Materials Report*, ...

NPD DisplaySearch, *TFT LCD Components and Materials Market Faces Twin Challenges of Declining Revenues and Dramatic Changes in Component Technologies*, March 18, 2009

NPD DisplaySearch, *TFT LCD Polarizer Revenue Expected to Fall for the First Time in 2009; Nitto Denko Remains #1 TFT LCD Polarizer Supplier*, January 20, 2009

NPD DisplaySearch, *Updated All-in-One PC Forecast Mirrors Mini-Note Growth, with 13% CAGR from 2010-2015*, April 26, 2010

NPD DisplaySearch, *LG Display Led 2010 Unit and Area Shipments, While Samsung Maintains Lead in Revenues,* February 14, 2011

NRDC (2015), THE BIG PICTURE: ULTRA HIGH-DEFINITION TELEVISIONS COULD ADD $1 BILLION TO VIEWERS' ANNUAL ELECTRIC BILLS, Nov. 2015, available from https://www.nrdc.org/sites/default/files/uhd-tv-energy-use-report.pdf , last viewed 20/04/18

Pall Corporation, *Photolithography Filtration for Display Manufacturing*, ...

Paul Semenza, *Display Glass: Bigger, Thinner, and Stronger*, Information Display Materials issue Vol.28 no.1, January 2012

Peetersa J., Vanegasa P. et al. Closed loop recycling of plastics containing Flame Retardants. Resources, Conservation and Recycling 84 (2014) 35–43

Peeters JR, et . Active disassembly for the endof-life treatment of flat screen televisions: challenges and opportunities. In: Proceedings of EcoDesign 2011: 7th international symposium on environmentally conscious design and inverse manufacturing; 2011. p. 535–40.

Perrine Chancerel, *Substance flow analysis of the recycling of small waste electrical and electronic equipment,* An assessment of the recovery of gold and palladium, Berlin, 2010

Pete Pachal, *Is plasma TV dead?,* May 11, 2012

Pete Putmanon, *Buy a Plasma TV While You Can*, July 19, 2012

Photronics, Inc., *Analyst / Investor Day*, September 8, 2011

PMR, *Construction sector in Poland, TPV AOC to build plant in Gorzow*, 2006-07-11

POLINARES EU policy on natural resources, *POLINARES working paper n. 39; Fact Sheet: Indium* , March 2012

Pradeep Chakraborty, *High-brightness LED market value in 2011 estimated at $9 billion; LED TV backlight market value dropped by 18 percent from 2010*, August 24, 2011

Prague Daily Monitor, *Taiwan's Pegatron Czech to sack most of its 1,500 staff,* February 11, 2011

Prophoto GmbH, *Trends im foto- und imagingmarkt Photokina 2012*, 2012

Quincy Liang, *Hon Hai Precision Wins Samsung's Order for 5 M. LCDTVs,* Tapei, February 1, 2010

Rasmus Larsen, *2011 TV MARKET SHARE REPORT,* 16 February 2012

Rasmus Larsen, *JAPAN DISPLAY BEGINS PRODUCTION,OLED FROM 2013*, April 3, 2012

Regulation (EC) No 106/2008 of the European Parliament and of the Council of 15 January 2008 on a Community energy-efficiency labelling programme for office equipment (recast version), OJ 13.2.2008, L39, p.1-7.

Ricky Tu, *Digitimes Research: Iljin Display expected to become number one touch screen supplier in Korea by the end of 2012*, Taipei, December 27, 2012

Rodney Chan, CES 2013: Corning to showcase Gorilla Glass 3, January 4, 2013

Roze E, Meijer L, Bakker A, Van Braeckel KNJA, Sauer PJJ, Bos AF. 2009. Prenatal exposure to organohalogens, including brominated flame retardants, influences motor cognitive, and behavioral performance at school age. Environ Health Perspect 117:1953–1958.

SANJU KHATRI, *Digital Signage and Professional Display Market Set for Solid Growth in 2012,* April 20, 2012

Semiconductor today, *Aixtron grows revenue 24% in Q2, as order backlog hits €250m*, July 29, 2010

Sharp Corporation, *Sharp Sustainability Report 2012*

Sharp Manufacturing Poland Ltd., *Environmental Site Report FY2012*

SHARP, *Sharp to Introduce PN-K321 LCD Monitor Featuring the Industry's Thinnest*2 Design in a High-Resolution 4K2K Display,* November 28, 2012

Skyscrapercity, *China televisions and panels industry updates*, April 22, 2011

SMG Indium Resources Ltd., *The indium market*, 2010

SMG Indium Resources Ltd., *Indium Fact Sheet*, January 16, 2013

SolidState Technology, *LEDs to get backlighting market share help from rising CCFL costs*, August 13, 2012

Sony Global, Company data URL: http://www.sony.net/SonyInfo/News/Press/201206/12-0628E/

Sony, *LED backlight technology, ...*

Speight, James G. (2017), Environmental Organic Chemistry for Engineers, Elsevier, ISBN 978-0-12-804492-6

Steve Sechrist, *LED Backlit TVs to Dominate in 2012,* May 22, 2012

Stobbe, L. (Fraunhofer Institute IZM, contractor), Preparatory Study “Televisions”(Lot 5), Report for Tender No. TREN/D1/40 lot 5-2005 (Ökoinstitut)Sumitomo chemical, *CSR REPORT 2012*

TCL Multimedia Technology Holdings Limited, *LCD TV Sales Volume up 26.8%, Reaching 1,502,625 Sets in November The proportion of LED Backlight LCD TV in the PRC market jumped to 99.7%,* December 6, 2012

TechniSat Digital GmbH, *TechniSat baut Standort Staßfurt aus!,* June 18, 2009

The European Commission, *" Discussion paper on the review of the Ecodesign and Energy Labelling Regulations for television and on the draft Regulation on electronic displays, including computer monitors*", presented at the CF meeting of 8 October 2012

Tom Lo, Digitimes Research: *Taiwan makers to see 17.6% drop in 2012 LCD TV shipments*, Taipei, November 23, 2012

Tom Mainelli, Ron Glaz, *Digital Photo Frame 2008-2012 Forecast: Special Study, July 2008*, IDC #213237, Volume: 1, Tab: Markets

Tony Huang, *2H 2012 global TFT panel market forecast*, Taipei, Thursday 23August 2012

Tony Huang, *Digitimes Research: China-based panel makers expected to extend influence in the TV panel market,* Taipei, January 2, 2013

Tony Huang, *Digitimes Research: Large-size TFT LCD panel unit shipments to decrease 3.5% in 2013*, Taipei, November 27, 2012

Tony Huang, *Digitimes Research: Panel makers trends in 2012 and 2013,* Taipei, November 30, 2012

Tony Huang, *Ultra HD TV panel shipments expected to reach 10 million in 2014*, Taipei, January 14, 2013

Toppan Technical Design Center CO.,Ltd., *Colour filters for LCD's, ...*

Toppan Technical Design Center CO.,Ltd., *Photomasks for semiconductors, ...*

Treaty on the functioning of the European Union (TFEU) which entered into force on 1st December 2009 (the content of article 95 TEC was moved to article 114 TFEU), replaced Treaty on the European Communities (TEC)

Turyk ME, Persky VW, Imm P, Knobeloch L, Chatterton R, Jr., Anderson HA. 2008. Hormone Disruption by PBDEs in Adult Male Sport Fish Consumers. Environ Health Perspect. 2008 Dec; 116(12): 1635–1641.

U.S. Geological Survey, *Mineral Commodity Summaries, Indium*, January 2011

US Environmental Protection Agency, US Energy Star database pc monitors, extract Dec. 2012.

US Environmental Protection Agency, US Energy Star database televisions, extract Dec. 2012.

Vanegas P., Peeters J. R., Cattrysse D., Duflou J. R. (ku Leuven), Paolo Tecchio P., Mathieux F., Ardente F. (JRC) (2016), Study for a method to assess the ease of disassembly of electrical and electronic equipment - Method development and application to a flat panel display case study - Study, Joint Research Centre, ISBN 978-92-79-58388-9

VDMA, European Technology: Flat Panel Displays, November 2006

VINCENT GU, Domestic LCD TV Consumption in China Retreats Dramatically, November 16, 2012

Wagner F., Peeters J. et al. Evaluation of the Quality of Postconsumer Plastics Obtained from Disassembly-Based Recycling Strategies. Polymer Engineering and Science, 2017, DOI 10.1002/pen

White, P. et al., Environmental, Technical and Market Analysis Concerning the Eco-design of Television Devices, European Commission Joint Research Centre, Institute for Prospective Technological studies (JRC-IPTS), 2006

Yanhua Lu, Yiping Wang, Li Zhu, Qi Wang, *Enhanced performance of heat recovery ventilator by airflow-induced film vibration (HRV performance enhanced by FIV)*, International Journal of Thermal Sciences 49 (2010) 2037-2041

Yole Développement SA, *LED Front-End Manufacturing*, 2012

Yoo Hyeong-Joon, *Korean CCFL Production Capacity, Overtook By Taiwan*, 2007/05/10