European Commission

JRC TECHNICAL REPORTS

Development of European Ecolabel and Green Public Procurement Criteria for Televisions

TECHNICAL REPORT, TASK 3

Technical analysis

(Draft) Working Document

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August 2013

Joint Research Centre

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This publication is a Technical Report by the Joint Research Centre of the European Commission.

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INTRODUCTION

This draft Task report is intended to provide the background information for the revision of the EU Ecolabel criteria for televisions. The study has been carried out by the Joint Research Centre's Institute for Prospective Technological Studies (JRC-IPTS) with technical support from the Öko-Institut e.V. (OEKO). The work is being developed for the European Commission's Directorate General for the Environment.

The EU Ecolabel criteria form key voluntary policy instruments within the European Commission’s Sustainable Consumption and Production and Sustainable Industrial Policy (SCP/SIP) Action Plan and the Roadmap for a Resource-Efficient Europe. The Roadmap seeks to move the economy of Europe onto a more resource efficient path by 2020 in order to become more competitive and to create growth and employment. The EU Ecolabel promotes the production and consumption of products with a reduced environmental impact along the life cycle and is awarded only to the best (environmental) performing products in the market.

An important part of the process for developing or revising Ecolabel criteria is the involvement of stakeholders through publication of and consultation on draft technical reports and criteria proposals and through stakeholder involvement in working group meetings. This document sets the scene for the discussions planned to take place at the two working group meetings planned in 2013/2014.

This draft preliminary Task 3 report addresses the requirements of the Ecolabel Regulation No 66/2010 for technical evidence to inform criteria revision. It consists of a technical analysis of existing lifecycle assessment studies revealing the environmental hotspots of televisions. Together with the scope, definitions and description of the legal framework (Task 1), a market analysis (Task 2) and input from stakeholders, the information will be used to determine the improvement potential and focus for the revision process (Task 4) and present an initial set of criteria proposals (Task 5).

3. LIFE CYCLE ANALYSIS OF TELEVISIONS

The main requirement of the EU Ecolabel is that criteria should be based on scientific evidence and should focus on the most significant environmental impacts during the whole life cycle of products. According to the Communication 'Building the Single Market for Green Products' from the EU Commission (COM (2013) 196), in general better information on the environmental performance of products should be facilitated. This should be done by gradually incorporating the Product Environmental Footprint (PEF) methodology as appropriate inter alia in its EU Ecolabel policies. This also includes the use of the International Reference Life Cycle Data System (ILCD) Handbook, which provides technical guidance for detailed LCA studies and the technical basis to derive product category-specific criteria. In the current revision process of Ecolabel criteria for televisions, these methods references will be taken into account within the following 'Technical Analysis'.

The purpose of this chapter is to respond to this requirement by using the best available scientific evidence to identify the environmental "hot spots" in the life cycle of televisions.

3.1 Overview of LCA studies on Televisions

In a first step, relevant literature regarding the environmental assessment and improvement potential of televisions has been identified and critically reviewed regarding their robustness of the results (methodology, data quality, age etc.).

This section presents an overview of existing LCA studies together with an initial screening categorising them according to the following quality criteria:

- Subject of the studies: The analysed products should have representative features of the product group, sub-categories, technologies or sizes.
- Time-related coverage of data: it refers to the year the inventory data of the analysis is based on; studies should ideally be less than 4 years old

- Study type: Studies should be based on a comprehensive LCA indicator set, ideally reflecting the Commission's Product Environmental Footprint (PEF) methodology or recognised LCA methodologies.
- Impact assessment: which environmental impacts are considered in the study?
- Reliability: Information on data quality provided by the study authors; studies should ideally be subject to an external critical review

The following table provides an overview of the screening results regarding LCA studies on televisions.

Table 1: Overview of LCA studies on televisions

Source	Title	Subject of the study	Functional unit	System boundary	Time related coverage	Study type	Impact assessment	Reliability		Notes
								Data quality	External critical review?	
Huulgaard et al. 2013	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	One 32-inch and one 46-inch LCD with LED backlight	One 32-inch and one 46-inch LCD with LED backlight with 12 years lifetime[1]	The complete life cycle	2010/2011	Traditional LCA from cradle to grave	The Stepwise2006 with midpoint and endpoint	The time-related, geographical and technological representativeness are described.	Not specified	Paper in Journal of Life Cycle Assessment
Bakker et al. 2012	Rethinking Eco-design Priorities; the case of the Econova television	42-inch LED-backlit LCD TV	One television, providing 3 hours and 12 minutes of television per day (of which 25% in eco-mode) and remaining in standby mode for the rest of the day, over a period of 6 years	The complete life cycle	2010 (assumed)	A fast-track LCA	Recipe indicator with millipoints (mPts) as unit.	Not specified	Not specified	Paper in EGG 2012 No absolute results, only ReCiP Points.
Thomas et al. 2011	Preliminary assessment for global warming potential of leading contributory gases from a 40-in. LCD flat-screen Television	40-inch LCD flat-screen TV	One 40-in. LCD flat-screen television weighing 12 kg	Cradle-to-gate stage and use stage	NF_3: 2008 (IPCC Tier 2 method) Production of LCD flat screen based on 1997-2000 (Socolof et al. 2005)	PCF (without end-of-life)	GWP taking NF3 into account	Not specified	Not specified	Paper in Journal of Life Cycle Assessment NF3 was analysed
Hischier & Baudin	LCA study of a plasma	42-inch Plasma	A 42-inch (=107 cm) PDP	The complete	2002-2007 (Literature)	Traditional LCA from	1) CML method: ARD, GWP, ODP,	Not specified	The manuscript was reviewed	Paper in Journal of

[1] A sensitivity analysis is carried out on the source of electricity and the lifetime of the TV.

Source	Title	Subject of the study	Functional unit	System boundary	Time related coverage	Study type	Impact assessment	Reliability		Notes
								Data quality	External critical review?	
2010	television device	TV	television device	life cycle		cradle to grave	PCOP, AP, EP, HTP, FAETP, MAETP, TETP 2) EI'99		by Prof. Lorenz Hilty.	LCA Life cycle inventory results associated with produc-tion, distribu-tion, use and end-of-life are listed. Comparison of PDP, LCD and CRT tech-nology is given with regard to impacts.
Feng & Ma 2009	The energy consumption and environmental impacts of a colour TV set in China.	CRT	The functional unit of this system is 10,000 general colour TV sets that are 25 inches diagonally and 30 kg in mass.	The complete life cycle	Not specified	Traditional LCA from cradle to grave	GWP, AP, EP,PCOP, bulk waste, emissions related to soot and ashes	Data quality described: "The data are reviewed and verified, based on the best knowledge available in China". Data sources are described.	Not specified	The study examines CO2, SOx, waterborne waste such as BOD and COD and solid waste
EuP Lot 5 2007	EuP Preparatory Study “Televisions” (Lot 5)	29-inch CRT TV, 32-inch LCD TV, 42-inch PDP TV	One 29-inch CRT TV, one 32-inch LCD TV, one 42-inch PDP TV with 10 year lifespan	The complete life cycle	Not specified	Based on the LCA approach (MEErP)	GER, GWP, ODP, AP, EP, VOC, POP, Heavy metals in air and in water, PAHs in air	Not specified	Open stakeholder consultation	
EPD AUO 2007	Certified Environmental Product Declaration Product: TFT-LCD Module-T420XW01	42-inch TFT-LCD Module	one TFT-LCD Module unit with 42- inch	Cradle to gate	2007	Based on the LCA approach	Manufacturing phase: resource used, GWP, AP, ODP, PCOP, EP, waste (non-hazardous & hazardous)	Not specified	Third party verifier: Environment and Development Foundation in Taiwan	EPD based on the PCR for TFT-LCD Module (PCR 2005:6)

Source	Title	Subject of the study	Functional unit	System boundary	Time related coverage	Study type	Impact assessment	Reliability		Notes
								Data quality	External critical review?	
EPD LG 2004	Certified Environmental Product declaration Product: TFT-LCD Module	32-, 37-, 42-inch TFT-LCD Modules	One TFT LCD Module unit with 32-, 37-, 42-inch	Cradle to gate	2004	Based on the LCA approach	Manufacturing phase: resource used, GWP, AP, ODP, PCOP, EP, waste (non-hazardous & hazardous)	Not specified	Third party verifier SP accredited by the Swedish Authority for Conformity Assessment and Control (SWEDAC).	EPD based on the PCR for TFT-LCD Module (PCR 2005:6)
Aoe 2003	Case study for calculation of factor x (eco-efficiency) — comparing CRT TV, PDP TV and LCD TV	32-inch CRT, LCD, PDP	32 inch type CRT, PDF and LCD TVs with installed BS/CS 110 digital tuner.	The complete life cycle	Power consumption: 2003	A Factor X (Eco-Efficiency) Tool. Three aspects were considered: the prevention of global warming; the effective utili-zation of resources; the use of nontoxic materials.	GHG emissions and supplied resources	Not specified	Not specified	Presented at EcoDesign 2003, 8-11 December, Tokyo

Note: GER: total energy; ADP: abiotic resource depletion; GWP: global warming potential; ODP: stratospheric ozone depletion; PCOP: photochemical oxidation potential; AP: acidification potential; EP: eutrophication potential; HTTP: human toxicity potential; FAETP: fresh-water aquatic ecotoxicity potential; MAETP: marine aquatic ecotoxicity potential; TETP terrestrial ecotoxicity potential

3.2 Evaluation of the comprehensiveness of the impact categories based on PEF methodology

The following Table 2 combines the information from PEF methodology[2] and the information of these studies evaluated.

[2] PEF-methodology: Default EF impact categories (with respective EF impact category indicators) and EF impact assessment models for PEF studies

Table 2: Evaluation of comprehensiveness based on PEF methodology

The Product Environmental Footprint (PEF)				Huulgaard et al. 2013	Bakker et al. 2012	Thomas et al. 2011	Hischier & Baudin 2010	Feng & Ma 2009	EuP Lot 5 2007	EPD AUO 2007	EPD LG 2004
EF Impact Category	**EF Impact Assessment Model**	**EF Impact Category indicators**	**Source**	**Stepwise 2006**	**ReCiPe**	**GWP**	**CML and Ecoindicator 99**	**n.A.**	**MEErP**	**n.A.**	**n.A.**
Climate Change	Bern model - Global Warming Potentials (GWP) over a 100 year time horizon.	kg CO2 equivalent	Intergovernmental Panel on Climate Change, 2007	+[3]	+[4]	+[5]	+[5]	- (only CO2, CH4, NOx and CO are taken into account)	- IPCC 2001	-[6]	-[6]
Ozone Depletion	EDIP model based on the ODPs of the World Meteorological Organization (WMO)	kg CFC-11 equivalent	WMO, 1999	- Based on IMPACT 2002+	- ODP is taken into account, but based on ReCiPe method.	0	+	0	- Based on the Regulation (EC) No 2037/2000[7]	-	-
Ecotoxicity for aquatic fresh water	USEtox model	CTUe (Comparative Toxic Unit for ecosystems)	Rosenbaum et al., 2008	- Based on IMPACT 2002+	- FAETP is taken into account, but	- FAETP is taken into consideration,	- FAETP is taken into consideration,	0	0	0	0

[3] Although a 100 year time horizon is not explicitly mentioned, we assume that GWP100 is investigated

[4] The midpoint in kg CO2e was calculated and further calculated into "Human health damage" and "Ecosystem Damage". The ILCD handbook states that there is a fine consistency between midpoint and endpoint methods, since the endpoint default method builds directly on the recommended midpoint default method.

[5] Although a 100 year time horizon and IPCC 2007 are not explicitly mentioned, we assume that it is compliant with PEF method.

[6] There is no description which impact assessment method is used. We assume that it based on IPCC 2001.

[7] REGULATION (EC) No 2037/2000 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 June 2000 on substances that deplete the ozone layer

The Product Environmental Footprint (PEF)				Huulgaard et al. 2013	Bakker et al. 2012	Thomas et al. 2011	Hischier & Baudin 2010	Feng & Ma 2009	EuP Lot 5 2007	EPD AUO 2007	EPD LG 2004
EF Impact Category	**EF Impact Assessment Model**	**EF Impact Category indicators**	**Source**	**Stepwise 2006**	**ReCiPe**	**GWP**	**CML and Ecoindicator 99**	**n.A.**	**MEErP**	**n.A.**	**n.A.**
					based on ReCiPe method	but the source is based on CML method.	but the source is based on CML method.				
Human Toxicity - cancer effects	USEtox model	CTUe (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008	- Based on IMPACT 2002+	- HTP is taken into account, but based on ReCiPe method.	- HTP is taken into consideration, but the source is based on CML method.	- HTP is taken into consideration, but the source is based on CML method.	0	0	0	0
Human Toxicity – non-cancer effects	USEtox model	CTUe (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008	- Based on IMPACT 2002+	0	0	0 (no difference between cancer and non-cancer effects)	0	0	0	0
Particulate Matter/Respiratory Inorganics	RiskPoll model	kg PM2.5 equivalent	Humbert, 2009	- Based on IMPACT 2002+	- is taken into account, but based on ReCiPe method	0	0	0	0	0	0
Ionising Radiation – human health effects	Human Health effect model	kg U235 equivalent (to air)	Dreicer et al., 1995	- Based on IMPACT 2002+	- is taken into account, but based on ReCiPe method	0	0	0	0	0	0
Photochemical Ozone Formation	LOTOS-EUROS model	kg NMVOC equivalent	Van Zelm et al., 2008 as applied in ReCiPe	- Based on EDIP 2003	+	0	- POCP is taken into consideration, but the source is based on CML method.	- Only CO and CH4 are taken into account.	0	-	-

The Product Environmental Footprint (PEF)				Huulgaard et al. 2013	Bakker et al. 2012	Thomas et al. 2011	Hischier & Baudin 2010	Feng & Ma 2009	EuP Lot 5 2007	EPD AUO 2007	EPD LG 2004
EF Impact Category	**EF Impact Assessment Model**	**EF Impact Category indicators**	**Source**	**Stepwise 2006**	**ReCiPe**	**GWP**	**CML and Ecoindicator 99**	**n.A.**	**MEErP**	**n.A.**	**n.A.**
Acidification	Accumulated Exceedance model	mol H+ eq	Seppälä et al.,2006; Posch et al., 2008	- Based on EDIP 2003	- AP is taken into consideration, but the source is based on ReCiPe method.	0	- AP is taken into consideration, but the source is based on CML method.	- Only SO2 and NOx are taken into account	- AP is taken into account, based on European Community legislation and the Gothenburg Protocol	-	-
Eutrophication – terrestrial	Accumulated Exceedance model	mol N eq	Seppälä et al.,2006; Posch et al., 2009	- Based on EDIP 2003	0	0	- EP is taken into consideration, but the source is based on CML method (no difference between aquatic and terrestrial eutrophication)	0	0	-	-
Eutrophication – aquatic	EUTREND model	fresh water: kg P equivalent marine: kg N equivalent	Struijs et al., 2009 as implemented in ReCiPe	- Based on EDIP 2003	- EP is taken into consideration, but the source is based on ReCiPe method.	0		- Only NOx and COD and N are taken into account	- EP is taken into account, but based on CML1992		
Resource Depletion – water	Swiss Ecoscarcity model	m3 water use related to local scarcity of water	Frischknecht et al., 2008	0	0	0	0	0	- Water used, not related to local scarcity	0	0
Resource Depletion – mineral, fossil	CML2002 model	kg antimony (Sb) equivalent	van Oers et al., 2002	Mineral extraction is taken into account based on IMPACT 2002+	- Is taken into account, but based on ReCiPe Method.	0	+	0	0	0	0

The Product Environmental Footprint (PEF)				Huulgaard et al. 2013	Bakker et al. 2012	Thomas et al. 2011	Hischier & Baudin 2010	Feng & Ma 2009	EuP Lot 5 2007	EPD AUO 2007	EPD LG 2004
EF Impact Category	**EF Impact Assessment Model**	**EF Impact Category indicators**	**Source**	**Stepwise 2006**	**ReCiPe**	**GWP**	**CML and Ecoindicator 99**	**n.A.**	**MEErP**	**n.A.**	**n.A.**
Land Transformation	Soil Organic Matter (SOM) model	Kg (deficit)	Milà i Canals et al., 2007	0	- Agricultural land occupation , Urban land occupation, Natural land transformation are taken into account, but based on ReCiPe method	0	0	0	0	0	0
The number of environmental impacts categories that are investigated within the studies				16	A single endpoint for the hierarchic point of view is used (18 midpoint impacts build a single issue indicator as endpoint)	1	10 (CML)	6	10 (including emissions)	5	5
The number of impact categories that are the same as PEF but don't use the same methodology				12	11	0	5	4	5	5	5
The number of impact categories compliant with the PEF methodology, i.e. use the same methodology				1	1	1	3	0	0	0	0

* CFC-11 = Trichlorofluoromethane, also called freon-11 or R-11, is a chlorofluorocarbon.

** PM2.5 = Particulate Matter with a diameter of 2.5 µm or less.

*** NMVOC = Non-Methane Volatile Organic Compounds

**** Sb = Antimony

+ = compliant with the requirements of the PEF methodology

- = not compliant with the requirements of the PEF methodology

0 = not taken into account

3.3 Selection of LCA studies for further detailed analysis

The existing LCA studies on televisions (see Table 1) generally cover all relevant display technologies (CRT, LCD and plasma), different screen sizes as well as innovative market developments (LED backlight for LCD televisions). Several of the studies are based on the LCA approach and provide a broader range of impact categories. On the other hand, there are studies with focus on relevant specific aspects, e.g. NF_3 emissions, which will be taken into account.

To decide, which of the studies in Table 1 will be analysed in detail (see section 3.4), we have assessed and compared them regarding their quality. The first precondition for a further detailed analysis – besides the fact that they should not be older than four years – is that the LCA studies have to provide at least 5 different impact categories to avoid unilateral observation. Hence, certain PCF studies will be excluded for the further detailed analysis. Furthermore, the impact categories investigated in the LCA studies should be prescribed by the PEF methodology (see Table 2). The threshold of 5 applies to the general impact category and not to the source. That means that the summation of the last two rows in Table 2 should be larger or equal to 5.

3.3.1 LCA studies selected for further detailed analysis

Against this background, the following studies pass the quality check and will be further analysed in detail in the next section 3.4:

- **Huulgaard et al. 2013**: They investigated two LCD TVs concerning different electricity mix and the lifetime to demonstrate the change of proportion of life cycle phases. They reveal that it is necessary to set up requirements in the implementing measures of Ecodesign Directive that cover not only the use phase but more life cycle phases of the product in order to address the most important impacts.

- **Bakker et al. 2012**: This study answered to the question whether a dominant impact of certain electric and electronic products might not always be in the use phase. The LCA results presented are based on the ReCiPe indicator as a single score for the energy efficient Philips econova LED televisions. This study reveals certain findings from ecodesign strategies point of view. However, there is no evidence of the breakdown of impacts at component level and the breakdown of various impacts studied. Millipoints as unit in the ReCiPe are used as a single score differing from material, production, transport, use, and recycling. An eco-cost analysis is conducted.
- **Hischier & Baudin 2010**: They analysed the environmental impacts of a plasma television. The contributors associated with the production phase at component level are provided in percentages. Furthermore, the authors established the possibility for a relative comparison of PDP, LCD and CRT technologies with regard to environmental impacts based on the unit “per square inch”.

3.3.2 LCA studies chosen for supplementary evidence on environmental impacts

On the other side, the following LCA studies will be *excluded from a further detailed analysis* in section 3.4. Although they have a different focus and targets, however, some findings and conclusions regarding environmental hotspots in the life cycle of televisions might be relevant for the purpose of this study. Thus, *specific results* of these studies might be pointed out briefly in **section 3.5** if they seem relevant for the development of ecolabel criteria for televisions and complement the results of the detailed LCAs.

- Thomas et al. (2011) investigated merely the global warming potential of leading contributory gases from a 40 inch LCD TV with focus on the impacts of NF_3. As NF_3 used in the LCD manufacturing has a high GWP value, it might be interesting to look at the impacts of NF_3 separately.

- In the study by Feng & Ma 2009, only four impact categories were investigated. Moreover, CRT TVs were the object being investigated. The CRT technology is sharply decreasing, thus it will not be an extra focus of the further analysis. However, the difference in terms of environmental impacts between the display technologies will be evaluated based on Hischier & Baudin (2010).

Studies being older than 4 years will generally not be included in the further research. The TV technology has been developing rapidly. Hence, the outdated studies do not reflect current technology, e.g. Aoe 2003 (see Table 1) cited by Andrae & Andersen (2010) will be excluded from further analysis. However, the GWP results might be compared to the other studies to show the variety of results. Also the data basis of the EuP preparatory study Lot 5 (2007) is significantly older than 4 years. Further, regarding the overall result of EuP Lot 5, another study (van Rossem and Dalhammar, 2010) revealed that use phase has been overestimated, whereas the manufacturing phase has been underestimated.

Finally, the two EPD studies from manufacturers (AUO and LG) will not be further investigated, although their impact categories meet the threshold. The decision is based on the fact that only impacts associated with the manufacturing phase are analysed. Furthermore, the EPDs evaluate only the LCD module, not the whole TV sets, which is not directly comparable to the other studies.

3.4 Detailed analysis of the selected LCA Studies

3.4.1 Base parameters of the selected LCA studies

The corresponding objects investigated in the different LCA studies are outlined in the following table.

Table 3: Description of objects investigated and their characterisations

Studies	Title of the studies	Object investigated	Characterisation	Lifetime
Huulgaard et al. (2013)	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	The first TV is 46 inch in screen size and based on LED technology. The second TV is 32 inch in screen size and also based on LED technology. The first TV is installed on a wall bracket. The second TV is installed on a pedestal.	32" LCD TV: 10.81 kg 46" LCD TV: 52.5 kg	LCD: 12 years; 4hours watching time per day
Bakker et al. (2012)	Rethinking Eco-design Priorities; the case of the Econova television	Philips Econova LED television with 42", being the winner of the EISA (the European Imaging and Sound Association) Green Award in 2010.	The TV's backlit is using an edge-LED lighting.	LCD: 6 years; 3 hours and 12 minutes watching time per day, remaining time in standby mode.
Hischier & Baudin (2010)	LCA study of a plasma television device	A 42-inch plasma display panel (PDP)	Screen format: 16:9 Resolution: 1024x768 Luminosity: 1400 cd/m2 Contrast: 3000:1 Weight: 30.2 kg	PDP: 60,000 h – but with a loss of 50% of the luminosity after the first 30000 h LCD: 45,000 h CRT: 15,000 h

3.4.1.1 Goal and scope

The goal and scope of the selected studies are described in the Table 4. The definitions of goal and scope should be compliant with goal and scope of Task 3 in our study. As described at the beginning of this chapter, "*The purpose of this chapter is to respond to this requirement by using the best available scientific evidence to identify the environmental "hot spots" in the life cycle of televisions."*

The selected LCA studies have to be based on the ISO standards for life cycle assessment (ISO 14040 and 14044). A life cycle assessment analyses the environmental impacts of products from cradle to grave.

Table 4: Goal and scope of the studies

Studies	Title of the studies	Goal of the studies	Scope	Study Type
Huulgaard et al. (2013)	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	The aim is to conduct an environmental impact assessment of the two TVs to assess the importance of energy consumption in the use phase and what other hot spots can be identified.	A traditional LCA from cradle to grave	The approach taken in this paper is the consequential LCA approach. Consequential modelling is characterized by excluding constrained suppliers and avoiding allocation by system Expansion.
Bakker et al. (2012)	Rethinking Eco-design Priorities; the case of the Econova television	The aim of the paper is to test the validity of the "use phase" heuristic (defined as experience-based techniques for problem solving). Concerning the LCA part in this paper: A fast-track LCA was made to examine which life cycle phases of the Econova television have the greatest ecological impact.	From cradle to grave	A fast-track LCA. A fast track LCA is different from a "classic" LCA in terms of the output of a classical LCA being input for the fast-track calculations.
Hischier & Baudin (2010)	LCA study of a plasma television device	To present a revised and updated version of a diploma thesis (2006), which was to establish a detailed LCA study of PDP and comparison of the two competing technologies (CRT and LCD).	A traditional LCA from cradle to grave	LCA of a plasma TV Comparison of 3 technologies

3.4.1.2 *Functional units and system boundaries*

According to ISO 14040/44, the functional unit refers to a quantified performance of a product system for use as a reference unit in LCA studies. The system boundary describes which processes are taken into account in the LCA analysis and which processes are not.

Table 5: Functional units and system boundaries

Studies	Title of the studies	Functional Unit	System boundary
Huulgaard et al. (2013)	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	The functional unit is one TV including production phase, use phase and end of life.	The complete life cycle
Bakker et al. (2012)	Rethinking Eco-design Priorities; the case of the Econova television	One television, providing 3 hours and 12 minutes of watching time per day (of which 25% in eco-mode) and remaining in standby mode for the rest of the day, over a period of 6 years.	From cradle to grave
Hischier & Baudin (2010)	LCA study of a plasma television device	The complete life cycle of a 42-inch (=107 cm) PDP television device; produced in Asia, used during 8 years, 4 h/day, in Europe and recycled in a European state-of-the-art recycling system.	The complete life cycle

3.4.1.3 *Cut-off criteria*

According to the ISO 14040/44:2006 and ILCD Handbook, cut-off criteria should be documented in a LCA study, the reasons should be stated and the effect of cut off parts on results should be estimated.

Table 6: Cut-off criteria

Studies	Title of the studies	Cut-off Criteria (inclusion of mass, energy and environmental cut-off criteria)	Estimation of the effect of cut-off
Huulgaard et al. (2013)	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	Auxiliary materials are not included in the assessment, but are assumed to be small. Material losses are included in the production processes, but not in the assembly processes.	It is assumed that the effect is small.
Bakker et al. (2012)	Rethinking Eco-design Priorities; the case of the Econova television	Some cut-offs were made in the production of parts due to lack of data: rest materials; LEDs; sound system (magnet); photovoltaic; battery; USB cable and rest materials are not taken into account[8]	In total these cut-offs account for less than 1% of the total weight of materials, consist most probably of a mix of high and low impact processes, and are therefore not seen as a major loss in data.
Hischier & Baudin (2010)	LCA study of a plasma television device	No specified	No specified

3.4.1.4 *Allocation*

If any allocation is considered in the studies, it is outlined in the following table.

Table 7: Allocation applied

Studies	Title of the studies	Allocation parameter
Huulgaard et al. (2013)	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	Not relevant, since a consequential modelling is conducted, which avoids allocation by system expansion.
Bakker et al. (2012)	Rethinking Eco-design Priorities; the case of the Econova television	Not specified
Hischier & Baudin (2010)	LCA study of a plasma television device	Not specified

[8] This information is not documented in the paper by Bakker et al. 2012, but in the detailed master thesis by Ingenegeren (2011).

3.4.1.5 *Data quality requirements and data sources*

Data quality level and sources of primary and secondary data should be documented. The time-related, geographical and technological representativeness of the selected LCA studies are summarised in Table 8. Furthermore, the information on the data source including primary and secondary data is described in Table 9.

Table 8: Data quality requirements

Studies	Title of the studies	Time-related representativeness	Geographical representativeness	Technological representativeness
Huulgaard et al. (2013)	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	-32" TV: 2010 -46" TV: 2011	32" TV: production in Asia and the TV is assembled partly in Asia and Europe. 46" TV: components are produced in Asia, Europe and the USA. The assembly takes place in Europe. Both TVs are used under the electricity mix, which only includes European suppliers. The waste from both TVs is treated in Europe.	The criteria for selection were that the TVs had to be representative of the manufacturer's collection of TVs in terms of sales figures and technology. Based on the knowledge from the manufacturers, assumed that the two TVs are representative for the manufacturers' TV portfolio in terms of technology and screen size.
Bakker et al. (2012)	Rethinking Eco-design Priorities; the case of the Econova television	2011	Production of components: China and South Korea; Assembly and use: Europe	Early 2011, it was one of the best examples of eco-design for TVs.
Hischier & Baudin (2010)	LCA study of a plasma television device	Not clearly mentioned. The year of literature has a range of 2002-2006	Assembly: Asia (Korea, Japan) Final assembly site: Turkey Use: Central Western Europe End-of-Life: Swiss recycling system	PDP: state of the art (technology for 2009)

Table 9: Data sources

Studies	Title of the studies	Data sources of primary data	Data sources of secondary data
Huulgaard et al. (2013)	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	Data on components for the 32-inch TV were provided directly in spread sheets from the manufacturer, whereas the authors and the manufacturer of the TV disassembled a TV and gathered the data themselves for the 46-inch TV.	Ecoinvent 2.2 (2010) and other literature.
Bakker et al. (2012)	Rethinking Eco-design Priorities; the case of the Econova television	An Econova TV and its remote control were disassembled, weighed and the different materials were determined.	Ecoinvent 2.2 (2010) and other literature.
Hischier & Baudin (2010)	LCA study of a plasma television device	The components of a plasma device and their respective weights were identified by dismantling. The device is from the Swiss WEEE System at the end of its life.	Information from various international patents and further literature was used. Database: Ecoinvent V2.01

3.4.1.6 *Impact categories and impact assessment methods*

The environmental impacts considered and assessment methods applied are described in the following table.

Table 10: Impact categories and impact assessment methods

Studies	Title of the studies	Impact assessment methods	Impact categories
Huulgaard et al. (2013)	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	The Stepwise2006 with midpoint and endpoint	Stepwise2006: midpoint: -Global warming; -Respiratory inorganics; -Respiratory organics; -Human toxicity, carcinogens; -Human toxicity, non-carcinogenic -Ionizing radiation; -Ozone layer depletion: -Ecotoxicity, aquatic: -Ecotoxicity, terrestrial; -Nature occupation; -Acidification; -Eutrophication, aquatic; -Eutrophication, terrestrial; -Photochemical ozone; -Non-renewable energy; -Mineral extraction
Bakker et al. (2012)	Rethinking Eco-design Priorities; the case of the Econova television	ReCiPe	Only single score is provided.
Hischier & Baudin (2010)	LCA study of a plasma television device	1) CML 2) Eco-Indicator 99	1) CML method: ARD, GWP, ODP, PCOP, AP, EP, HTP, FAETP, MAETP, TETP 2) EI'99 (Eco-Indicator points: EIP)

3.4.1.7 *Assumptions*

While modelling, a series of assumptions has to be made. Documentation of assumptions is crucial to ensure the transparency and reproducibility of the results to some extent. The important assumptions are therefore summarised in the following table.

Table 11: Assumptions made while modelling

Studies	Title of the studies	Production	Distribution	Use	End-of-life
Huulgaard et al. (2013)	Ecodesign requirements for televisions – is energy consumption in the use phase the only relevant requirement?	The electricity used for the assembling of the TV, packaging and production of the components is the same as applied in the use stage. Only electricity used for aluminium production is the same as for the original dataset from Ecoinvent 2.2	The transport distances were assumed to be 0 km from 'Consumer' to 'WEEE Centre', 200 km from 'WEEE Centre' to 'Disassembly plant', 200 km from 'Disassembly plant' to 'Recycling Plant' and 500 km from 'Disassembly plant' to 'Metal recovery plant'. The transport of the packaging of the TV from consumer to the recycling plant was assumed to be 200 km.	12 years lifetime; 4h TV watching time per day, 20h TV standby time per day. TV is unplugged: 28 days per year. Fifty-eight percent of the electricity mix used for the modelling is wind based, because many of the European countries have decided to increase the share of wind-based electricity. The last 42% of the electricity mix used for the modelling is based on natural gas, biomass, hydro, geothermal and solar energy.	Collection rate: 100%. Printed wiring boards (PWBs), cables and LEDs go through a metal recovery process while the rest of the materials end up at recycling plants. It is assumed that there is no loss of materials in the disassembly process. Some components such as connectors and glass from the LCD module end in incinerators or landfill; for other components, the recycling rates vary from 77.9 % (wood) to 99 % (aluminium). For plastics, the efficiency is 92.5 %. The recycling efficiency for metals varies between 80 % (tin) and 99 % (copper).
Bakker et al. (2012)	Rethinking Eco-design Priorities; the case of the Econova television	The aluminium parts of the Econova consist of 60% post-industrial recycled aluminium.	Transport of components (produced in China and South Korea) to Europe (for assembly and use) is done by ship and airplane. Trucks are used to transport subassemblies and finished TVs within Europe	In the use phase, a second use scenario was calculated with a "best case" user, assuming the eco-mode would be used all the time, and the TV would be switched off completely after 3 hours and 12 minutes (assuming 0 hour of standby).	At the end of life it is assumed the TV is recycled, resulting in recycling credits for several parts.
Hischier & Baudin (2010)	LCA study of a plasma television device	Composition data of housing, insulation protection material, plasma panel, electronics, cables, packaging are from literature (Baudin 2006). The auxillaries and energy amount in assembly is roughly estimated based on the literature.	2500 km by lorry	4 h on per day (based on EuP) 8 years lifespan UCTE electricity mix is used Swiss electricity mix for a sensitivity analysis	An average transport distance (and a mix of transport mean) according to the Swiss recycling system (a state-of-the-art WEEE recycling system) is assumed Metal parts from housing: 100% recycling; 100% incineration-plasma panel; 100% incineration-capacitors; 100% to specific capacitor disposal process; electronics parts: 100% to a precious metal recovery process; 100% to cable recycling

Studies	Title of the studies	Production	Distribution	Use	End-of-life
					process; EPS 100% to incineration/corrugated board 100% recycling; Credits are given in all cases of secondary production, i.e. a similar amount of primary production of the respective material is given as credit. The electricity and heat produced in the incineration process results in a credit of the respective amount of electricity (as Swiss electricity mix) or heat (as heat from light fuel oil boiler).

3.4.2 Quality of assessment methods applied in the selected LCA studies

To provide an overall picture of the scientific robustness of the indicator sets used in the selected LCA studies, this chapter evaluates the assessment methods applied in the selected LCA studies based on the ILCD handbook (ILCD 2011).

The ILCD handbook on recommendations for life cycle impact assessment in the European context evaluates different impact methods and provides the following six criteria:

- Scientific criteria
  - Completeness of scope
  - Environmental relevance
  - Scientific robustness & Certainty
  - Documentation & Transparency & Reproducibility
  - Applicability
- Stakeholder acceptance criterion
  - Degree of stakeholder acceptance and suitability for communication in a business and policy contexts

The first five science based criteria are applied as a basis for the evaluation of the impacts methods. The following score according to ILCD handbook (2011) is used:

- A: Full compliance
- B: Compliance in all essential aspects
- C: Compliance in some aspects
- D: Little compliance
- E: No compliance

To facilitate the calculation of scores, we assume that A=5; B=4; C=3; D=2; E=1.

If there is B/C as the evaluation result, the average data (in this case: 3.5) is used.

Table 12: Quality of assessment methods applied in the selected LCA studies

	Studies	Hischer & Baudin 2010		Huulgaard et al. 2013	Bakker et al. 2012
Score based on the Tables in ILCD handbook 2011	**Impact methods**	**CML**	**Ecoindicator 99**	**Stepwise 2006**	**ReCiPe**
based on the Table 3	Climate change	24	18	Not evaluated in the ILCD handbook	23
Based on the Table 5	Ozone depletion	24	19		21
Based on the Table 7	Human toxicity	22	Not evaluated in the ILCD handbook		21
Table 11	Particulate matter/ respiratory inorganics	Not evaluated in the ILCD handbook	Not evaluated in the ILCD handbook		Not evaluated in the ILCD handbook
Table 13	Ionizing radiation	Not evaluated in the ILCD handbook	Not evaluated in the ILCD handbook		Not evaluated in the ILCD handbook
Table 14 and Table 15	Photochemical ozone formation	18.5	Not evaluated in the ILCD handbook		19.5
Table 16 and Table 17	Acidification	20.5	17		20
Table 18	Aquatic eutrophication	16.5	Not evaluated in the ILCD handbook		21.5
Table 19	Terrestrial eutrophication	16.5	19		Not evaluated in the ILCD handbook
Table 21	Ecotoxicity	Not evaluated in the ILCD handbook	Not evaluated in the ILCD handbook		22.5
Table 24	Land use	Not evaluated in the ILCD handbook	not applicable[9]		2
Table 27	resources	21	18		20
Total score		**163**	**91**		**170.5**
Possible maximum score = maximum score of scientific criteria (25) x number of categories covered in the corresponding methods		**=25x8=200**	**=25x5=125**	**Not applicable**	**=25x9=225**
Share $= \frac{\text{total score}}{\text{possible maximum score}}$		**81.5%**	**72.8%**	**Not applicable**	**75.8%**

[9] "Not applicable" refers to the impact category under the corresponding method is evaluated in the ILCD handbook, but the impact category is not considered in the studies.

3.4.3 Results of the selected LCA studies

Results from the study by Huulgaard et al. 2013

Table 13 shows the results of midpoint and endpoint of the LCA study by Huulgaard et al. 2013. From endpoint impact, it appears that GWP and respiratory inorganics potential are the environmental hot spots. Both of them together contribute with 76% and 79% to the total impact categories investigated. The other 14 environmental impact categories have very low contributions.

Table 13: Results of LCA of two TVs (Source: Huulgaard et al. 2013, Table 3)

Table 3 Summary of the life cycle impact assessment from cradle to grave of the 32- and the 46-in. TV. LCIA method: Stepwise2006, midpoint (H) (Weidema 2007; Weidema et al. 2007)

Impact category	Midpoint result			Endpoint result				
	Unit	32 in.	46 in.	Unit	32 in.	%	46 in.	%
Total	–	–	–	EUR2003	73	100	246	100
Global warming	kg CO_2-eq	386	1,334	EUR2003	32	44	111	45
Respiratory inorganics	kgPM2.5-eq	0.35	1.2	EUR2003	23	32	83	34
Respiratory organics	pers*ppm*h	0.21	0.76	EUR2003	0.05	0.07	0.19	0.08
Human toxicity, carcinogens	kg C_2H_3Cl-eq	16	40	EUR2003	4	6	11	4
Human toxicity, non-carc.	kg C_2H_3Cl-eq	20	61	EUR2003	5	7	16	7
Ionizing radiation	Bq C-14-eq	3,067	9,826	EUR2003	0	0	0.0	0
Ozone layer depletion	kg CFC-11-eq	4.74E-05	1.58E-04	EUR2003	0	0.01	0.02	0.01
Ecotoxicity, aquatic	ton TEG-eq w	51,621	200,028	EUR2003	0.18	0.50	1	0.58
Ecotoxicity, terrestrial	ton TEG-eqs	4,358	13,690	EUR2003	5	7	15	6
Nature occupation	m^2 agr. land	4.5	17	EUR2003	0.56	0.76	2	0.83
Acidification	m^2 UES	39	121	EUR2003	0.30	0.41	0.94	0.38
Eutrophication, aquatic	kg NO_3-eq	1.8	2.7	EUR2003	0.37	0.25	0.28	0.11
Eutrophication, terrestrial	m^2 UES	39	152	EUR2003	0.49	0.67	2	0.77
Photochemical ozone, vegetat.	m^2*ppm*h	2,341	8,736	EUR2003	0.87	1	3	1
Non-renewable energy	MJ primary	5,548	19,533	EUR2003	0	0	0	0
Mineral extraction	MJ extra	21.5	93	EUR2003	0.09	0.12	0.37	0.15

The results of the contribution analysis by Huulgaard et al. 2013 show that the production stage has the highest contribution for both TVs. The contribution from the production to GWP accounts for about 76% of the total GWP values for both TVs. As for the impact category “respiratory inorganics potential (RIP)”, the production phase has a proportion of 91% of the total values.

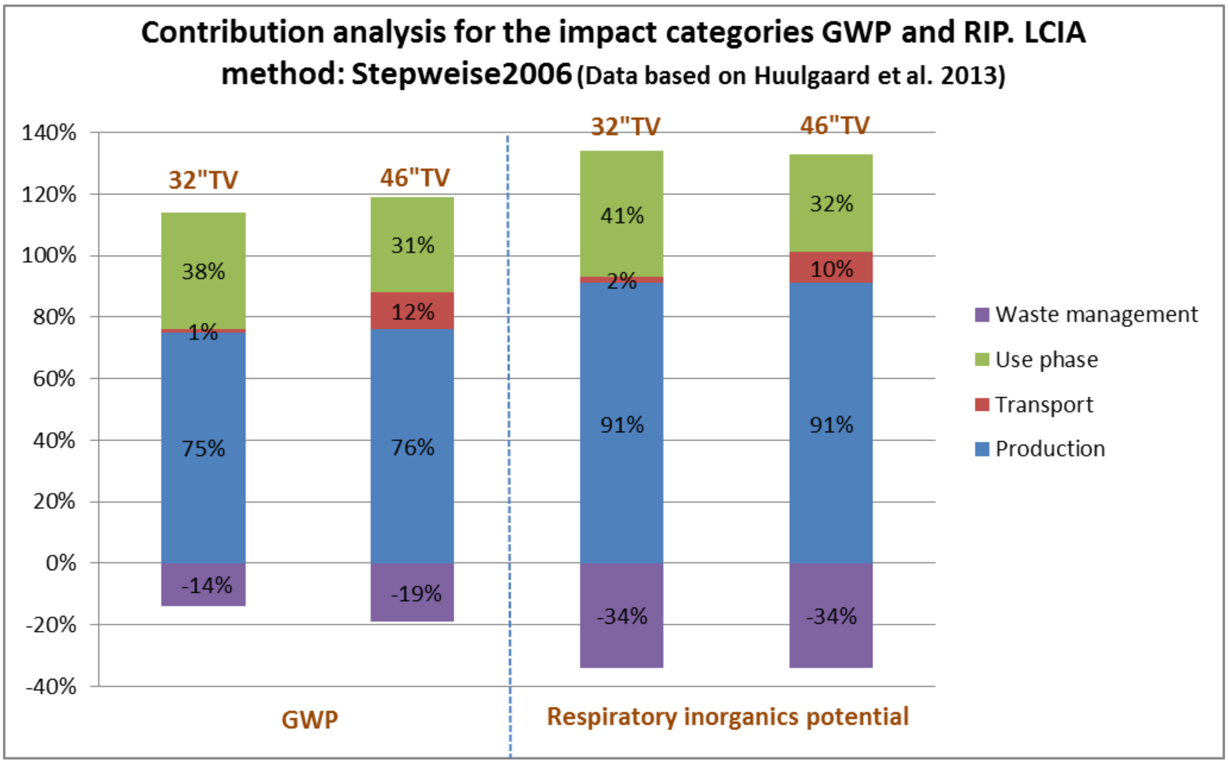


Figure 1: Contribution analysis for the impact categories GWP and RIP (Data based on Huulgaard et al. 2013)

Furthermore, a sensitivity analysis is carried out concerning the electricity mix and the lifetime of the TV. In the base scenario, the electricity mix provided only by European suppliers is taken into account, which has a high renewable energy proportion, such as wind, hydro, biomass etc. In the sensitivity analysis, coal-based electricity is applied. The following figures show the contribution for both TVs concerning GWP and RIP (respiratory inorganics potential) with lifetimes of 6, 10 and 12 years. It is no surprising that reduction of lifetime can affect the proportion of individual life phases. The analysis on 100% coal-based electricity shows that the production phase accounts for a range between 36% and 57% of the total GWP values, depending on the lifetime assumed. Therefore, the use phase has a proportion of between 46% and 68%. It shows that production phase, along with use phase, also has a significant share of the results.

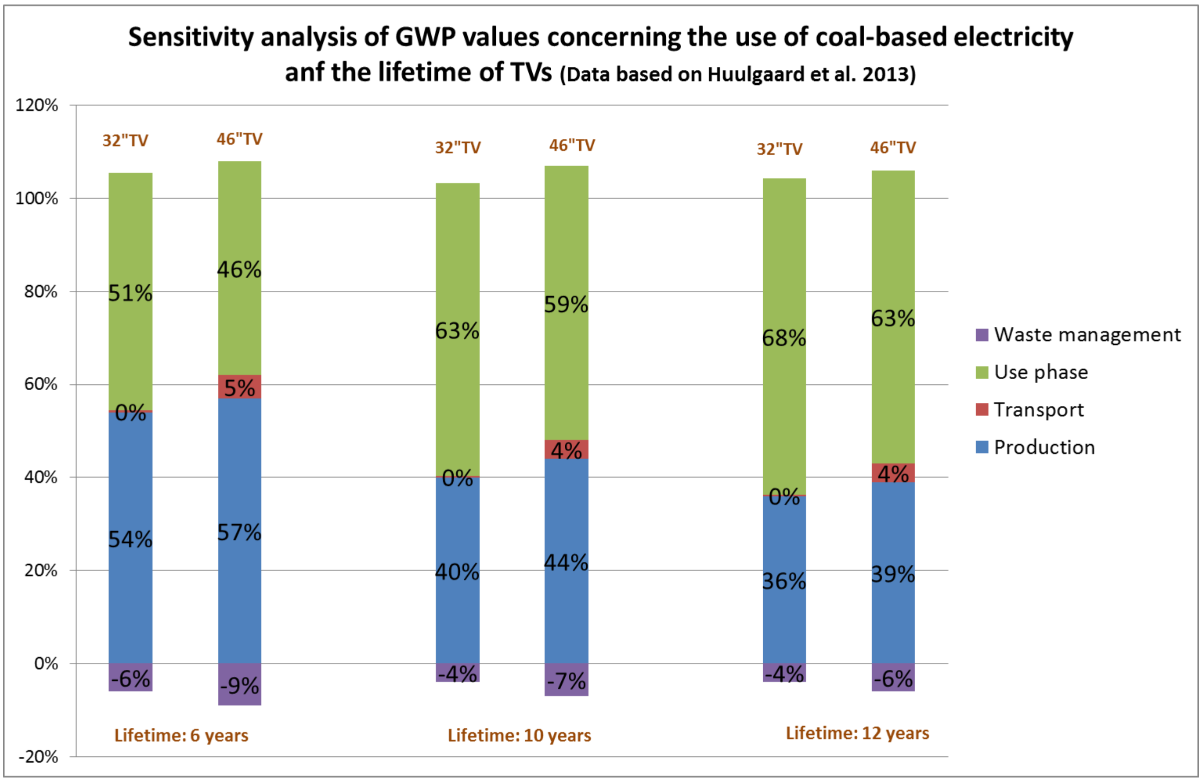


Figure 2: Sensitivity analysis of GWP values concerning the use of coal-based electricity and the lifetime of TVs (Data based on Huulgaard et al. 2013)

As for the RIP (respiratory inorganics potential), production phase accounts for a range between 47% (12 years) and 74% (6 years) of the total results, depending on the lifetime assumed, if the calculation of electricity is based on 100% coal.

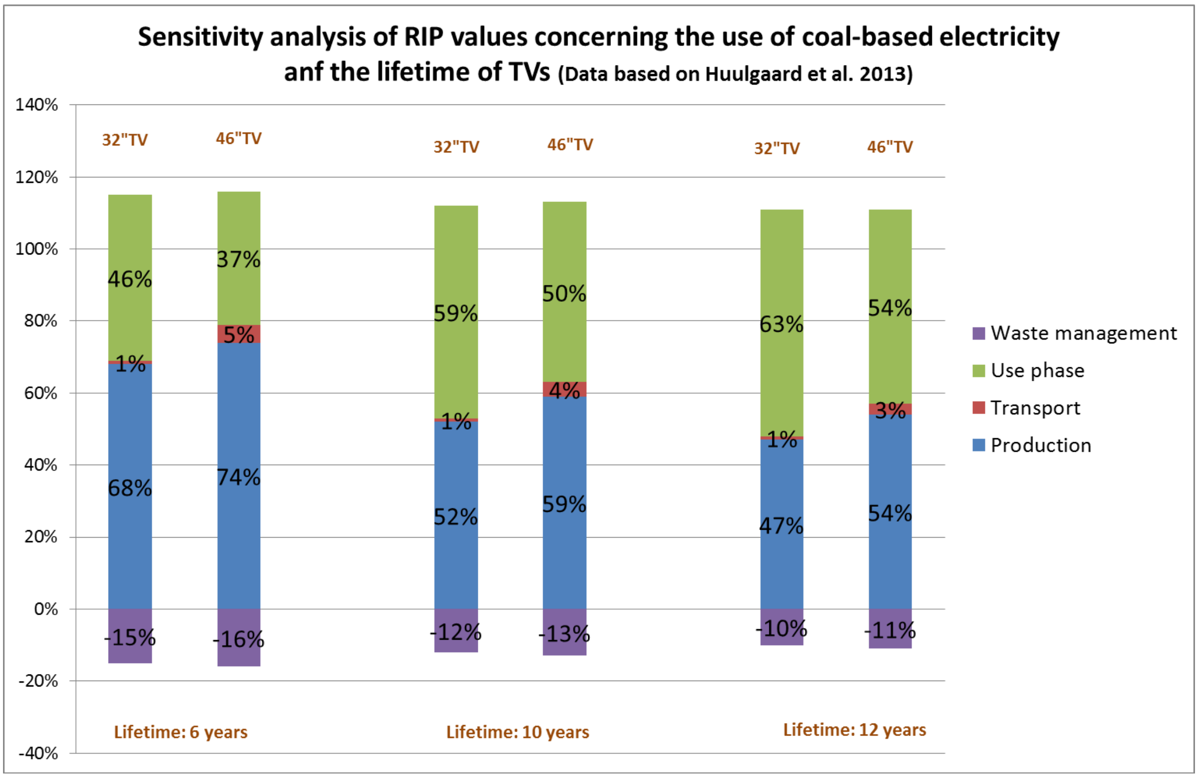


Figure 3: Sensitivity analysis of RIP values concerning the use of coal-based electricity and the lifetime of TVs (Data based on Huulgaard et al. 2013)

In a nutshell,

- The results of contribution analysis by Huulgaard et al. 2013 show that the production stage has the highest contribution for both TVs.
- GWP and respiratory inorganics potential are the most relevant environmental hot spots within the impact categories investigated. The other 14 environmental impact categories have very low contributions. The contribution from the production to GWP accounts for about 76% of the total GWP values for both LCD TVs. As for the impact category “respiratory inorganics potential (RIP)”, the production phase has a proportion of 91% of the total values.
- The analysis on 100% coal-based electricity shows that the production phase accounts for a range between 36% (12 years) and 57% (6 years) of the total GWP values, depending on the lifetime assumed. Therefore, the use phase has a proportion of between 46% and 68%. It shows that the use phase, along with

the production phase, has also a significant share of the results. As for the RIP (respiratory inorganics potential), production phase accounts for a range between 47% (12 years) and 74% (6 years) of the total results, depending on the lifetime assumed, if the calculation of electricity is based on 100% coal.

- It is found that in the case of TVs, the implementing measures under Ecodesign requirement are not addressing the most important impacts when exclusively setting requirements to energy consumption in the use phase. The results recommend that future Ecodesign requirements shall cover more life cycle phases of the product in order to address the most import impacts.

Results from the study by Bakker et al. (2012)

Figure 4 shows the LCA results across the life cycle based on the ReCiPe method. Two usage scenarios (different colour shades) are calculated. “Base case” is based on a use pattern with 3 hours and 12 minutes of television viewing times per day (of which 25% in eco-mode) and remaining in standby mode for the rest of the day, over a period of 6 years. “Best case” is assumed that the eco-mode would be used all the time and the TV would be switched off completely after 3 hours and 12 minutes (assuming 0 hours of standby modes). Under the “base case” usage scenario, the use phase is the dominant life cycle phase. If the “best case” is applied for the calculation, the dominant environmental impact switches to the manufacturing phase. Authors draw the following conclusions:

- The use phase is very sensitive to consumer behaviour. Significant environmental benefit can be achieved from stimulating “best case” user behaviour.
- Life span has also significant impact on use phase. The shorter the life span, the more likely it is that the dominant environmental impact is in the manufacturing phase.

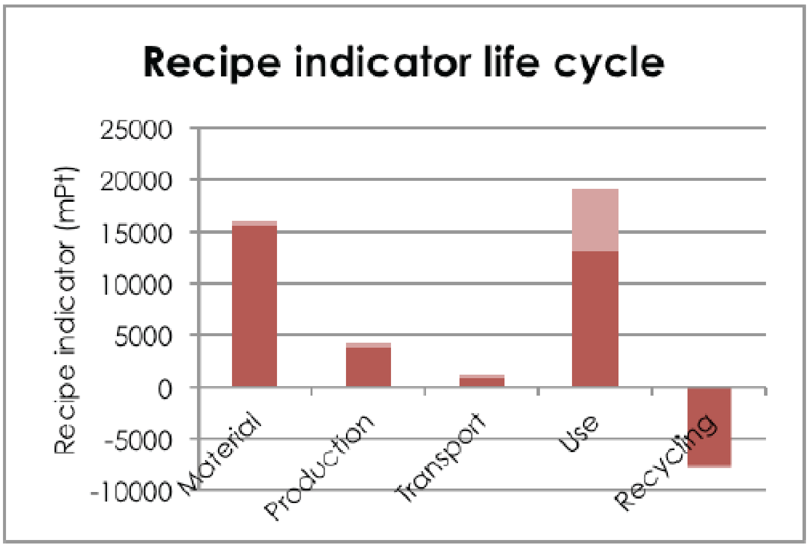


Figure 1 LCA of Econova using Recipe indicator

Figure 4: LCA results across the life cycle (source: Bakker et al. 2012)

On the component level, the PWB (only 5% of total weight) accounts for 25% of the ecological impact in the manufacturing phase and aluminium with 43% total weight has approximately 50% of the ecological impact.

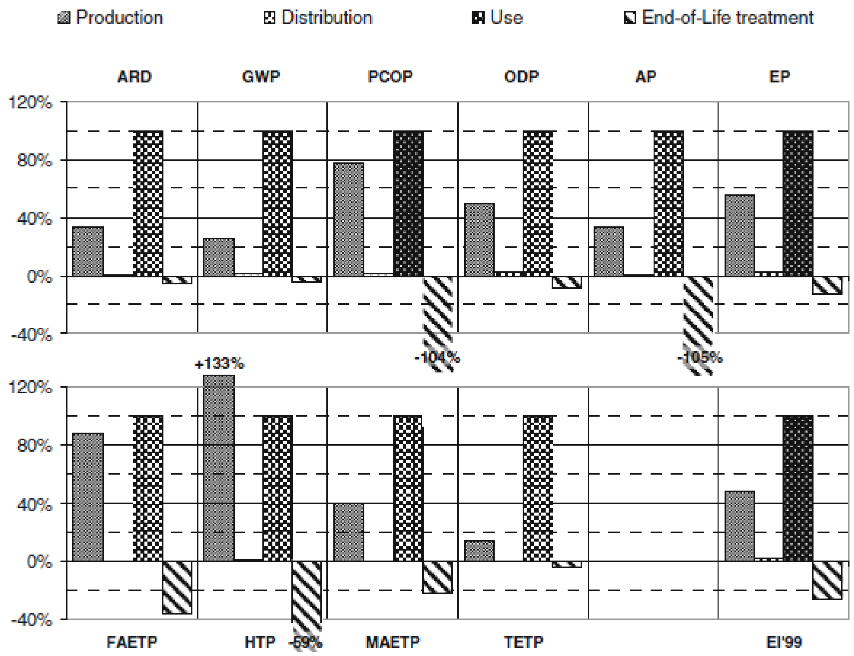
Moreover, authors reveal that a sustainability-oriented redesign should focus on both use and materials phases and should enable recycling wherever possible. The concrete redesign measures for the Econova televisions are listed below, since these measures might be interesting for the development of EU ecolabel criteria as well:

- To turn off the television is facilitated as the on/off-switch has been moved to the front panel, in clear view of consumers.
- Use of high-pressure die-cast aluminium (95% post-consumer scrap and 5% primary aluminium).
- Application of a powder coating onto the die-casting that does not hinder recycling.
- Minimization of the use of aluminium by replacing the back cover by an organically shaped back plate.
- The TV should be easy to disassemble.

Results from the study by Hischier & Baudin (2010)

The following tables summarises the results from the contribution analysis concerning the impacts differentiated from the life phases and impacts at component level. As described in section 3.4.1, Hischier & Baudin (2010) conducted not only a LCA study for PDP TV, but also a comparison analysis among PDP, CRT and LCD technology, which is also demonstrated below.

Table 14: LCA results of a plasma television device (Source: figures from Hischier & Baudin 2010)

Conclusions	Environmental impacts of the life cycle phases
Use phase dominates almost all environmental impacts investigated with the exception of human toxicity potential. Manufacturing phase has also a clearly higher environmental impact compared to the distribution and EoL. Within the End-of-life phase, the impact categories photochemical oxidation, acidification and human toxicity show a clearly higher benefit. That is due to the avoided primary production of aluminium (and its PAH emissions to air) in case of human toxicity or due to the avoided primary production of palladium (and its high SO_2 emissions to air) in case of PCOP and AP.	**Fig. 2** The complete life cycle of a plasma television device (relative to the impact of the use phase—calculated with the UCTE electricity mix). Shown are the following impact factors from the CML method: *ARD* abiotic resource depletion, *GWP* global warming potential, *ODP* stratospheric ozone depletion potential, *PCOP* photochemical oxidation potential, *AP* acidification potential, *EP* eutrophication potential, *HTP* human toxicity potential, *FAETP* freshwater aquatic ecotoxicity potential, *MAETP* marine aquatic ecotoxicity potential, *TETP* terrestrial ecotoxicity potential as well as the total of the Eco-Indicator '99 method (EI'99)  Environmental impacts dominating in the manufacturing phase: • Human toxicity Environmental impacts dominating in the use phase: • Abiotic resources • Global warming • Photochemical oxidation • Ozone layer depletion • Acidification • Eutrophication • Freshwater aquatic ecotoxicity • Marine aquatic ecotoxicity • Terrestrial ecotoxicity

<table>
<tr><th>Conclusions</th><th>Environmental impacts of the life cycle phases</th></tr>
<tr><td>Electricity mix, use pattern and power consumption of TVs determine the impact calculation in the use phase. The additional calculation on varying the electricity mix during the use phase shows that the impact can be changed considerably by changing the electricity mix, as shown the figure on the right side. If the Swiss electricity mix instead of the Union for the Coordination of Transmission of Electricity (UCTE)-mix is applied, the main contributor is changing from the use phase to the manufacturing phase.</td><td>

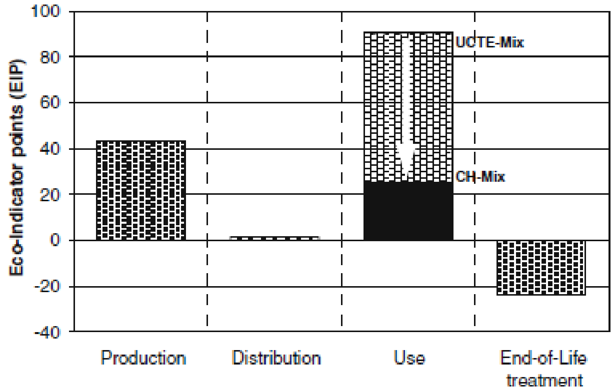


Fig. 3 Influence of a change in the electricity mix during the use phase on the complete life cycle of a plasma television device, expressed as the total of the Eco-Indicator '99

</td></tr>
<tr><td>Within the manufacturing phase, the main impact is due to the PWB (i.e. electronics), followed by housing. Within the total of the Ecoindicator 99 the PWB is responsible for almost 75% of the impact in the production phase. The second contributor is the housing with 15%, followed by the assembly activities (5%) and the actual PDP unit (3%).</td><td>

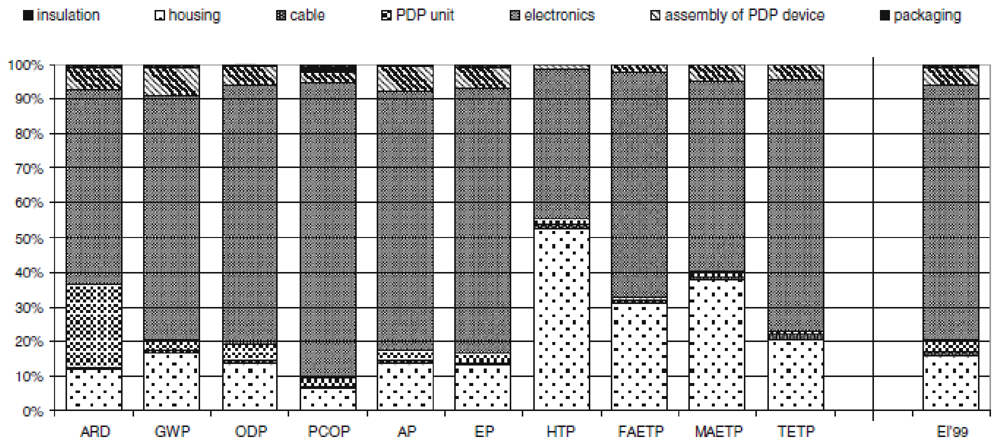


Fig. 4 The production phase of a plasma television device, expressed with CML and Eco-Indicator '99 method (for abbreviations of shown impact factors, see legend of Fig. 2)

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</table>

Table 15: Main contributors of the environmental impacts in the production phase for PDP televisions

Environmental impacts	Major contributors in the production phase
Abiotic resources	The actual PDP unit has an impact of more than 20% of the total impact due to the xenon gas in the filling.
Photochemical oxidation	PWB: -Due to the sulphur dioxide (SO_2) emissions to air in the production of palladium -Due to the air emissions of ethyl acetate and methyl ethyl ketone in the production process of the various electronic components (i.e. capacitors, inductors, etc.)
Acidification	PWB: Due to the SO_2 emissions to air in the production of palladium
Eutrophication	PWB: Due to the nitrogen oxides to air and COD emissions from the disposal processes in the wafer production.
Human toxicity	Housing: Due to the aluminium parts of the housing and there actually due to polycyclic aromatic hydrocarbons (PAH) emissions to air.
Freshwater aquatic ecotoxicity; Marine aquatic ecotoxicity; Terrestrial ecotoxicity	Housing: these aluminium parts are responsible for more than 80% of the impact coming from the housing. PWB: vanadium ion emissions to water due to the treatment of waste from the bauxite digestion are responsible for these impacts.

Figure 5 shows the results of the comparison between different technologies. The comparison is established based on the unit "per square metre of surface". Generally, all three technologies show a similar picture regarding the different life phases: use and production phases have the highest environmental impacts, while distribution and EoL are of minor importance.

Among the technologies, the LCD technology almost always shows the highest environmental impact, or an impact close to the highest impact. PDP technology shows the lowest impact, if the total score of Ecoindicator 99 is considered. In case of stratospheric ozone depletion, photochemical oxidation, acidification, eutrophication, human toxicity and freshwater ecotoxicity (6 of 10 impact categories investigated), PDP has the lowest impacts. Especially, the impact categories human toxicity and freshwater ecotoxicity show that the impact of the production of a LCD or CRT television is two and more times higher compared to that of a PDP television. The contributions to these impacts are summarised in the following table.

Table 16: Main contributors to the environmental impacts in the production phase of CRT and LCD televisions

Technology	Environmental impacts	Major contributors in the production phase
CRT	Human toxicity	Due to chrome (VI); arsenic and PAH emissions to air originating from the PWB and the chrome steel used in the CRT device
	Freshwater aquatic ecotoxicity	Due to nickel, cobalt and vanadium emissions to water
LCD	Human toxicity; Freshwater aquatic ecotoxicity	The assembly process of the LCD module as well as from the used amount of chrome steel and the PWB used
	Global warming	SF6 to air in the assembly stage
	Eutrophication	HF to air or vanadium and nickel to water
	Marine ecotoxicity	Nitrate, ammonium and COD values to water resulting from the waste water treatment in the assembly stage

The comparison refers to one unit CRT, LCD and PDP respectively. The different lifespan of these technologies is not taken into consideration.

Fig. 6 Comparison of PDP, LCD and CRT technology. Shown are relative values per square inch (i.e. per 6.45 cm²), with the value of the LCD screen being set as 100%, expressed with CML and Eco-Indicator '99 method (for abbreviations of shown impact factors, see legend of Fig. 2). In the *right lower corner*, absolute values for the Eco-Indicator '99 method are shown—again with the value of the LCD screen being set as 100%

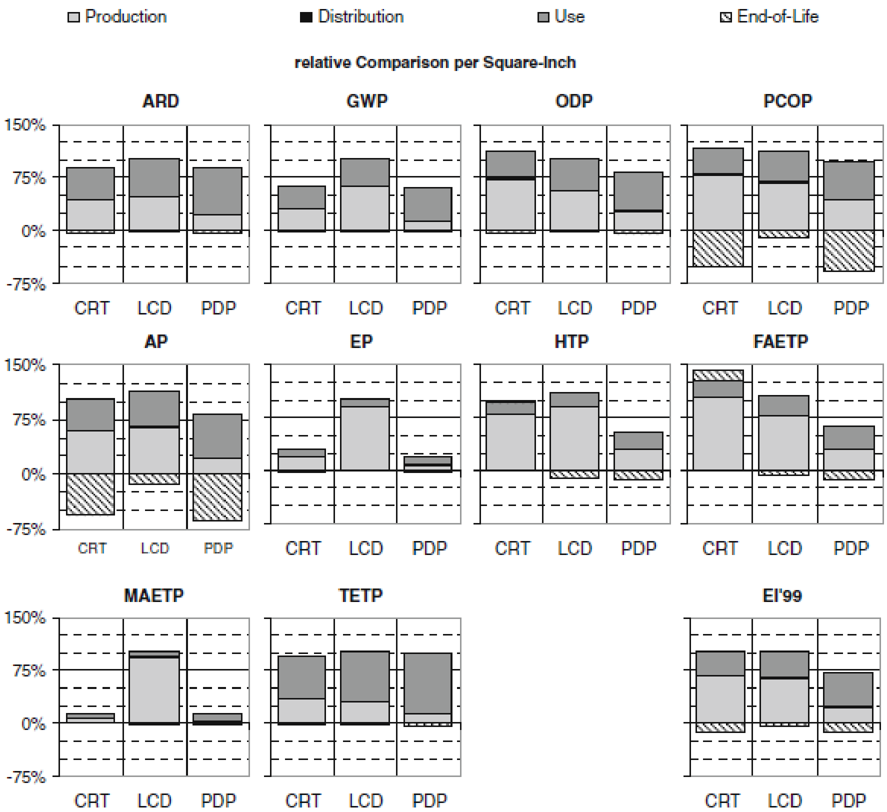

Figure 5: Comparison of PDP, LCD and CRT technology (source: from Hischier & Baudin 2010)

In a nutshell,

- All three technologies show a similar picture regarding the different life phases: use and production phases have the highest environmental impacts, while distribution and EoL are of minor importance.
- Among the different technologies, the LCD technology almost always shows the highest environmental impact, or an impact close to the highest impact. PDP technology shows the lowest impact, if the total score of Ecoindicator 99 is considered.
- For PDP televisions: The use phase dominates almost all environmental impacts, with the exception of human toxicity potential, in which the manufacturing phase is the dominating one. Furthermore, manufacturing has also a clearly higher environmental impact compared to distribution and EoL.

The environmental impact categories, especially photochemical oxidation, acidification and human toxicity in the manufacturing phase can be reduced, if EoL treatment is based on a sound management, since the secondary resources from recycling can avoid primary production. The impact of the use phase is caused by the energy consumption of the television. Electricity mix, use pattern and power consumption of the television determine the impact calculation. If the Swiss electricity mix is applied instead of the Union for the Coordination of Transmission of Electricity (UCTE)-mix, the main contributor is changing from the use phase to the manufacturing phase.

- For PDP televisions: Within the manufacturing phase, PWB has the greatest contribution to environmental impacts, followed by the housing. The high impacts from PWB are mainly due to the production process of the various electronic components, SO_2 emissions to air in the production of palladium, and wafer production as well as the treatment of waste from the bauxite digestion. Only in case of resource depletion the PDP unit has an impact of more than 20% of the total impact due to the xenon gas in the filling.
- For LCD televisions: The assembly process of the LCD module as well as the used amount of chrome steel and the PWB used are the main contributors at component level.
- For CRT televisions: The PWB and the chrome steel used in the CRT device are the main contributors at component level.

3.5 Findings from further studies

In this section, studies that do not comply with the quality criteria for LCA studies to be analysed as described in sections 3.1 and 3.2 are reviewed if they provide particular insight, e.g. because of the methodology or data used, or certain additional aspects on environmental hotspots not provided by the full LCA studies.

3.5.1 Overview of the GWP impacts

Table 17 shows the proportion of GWP values differentiated according to the life phases, as well as the absolute total value resulting from different studies. Depending on the different technologies, size of TVs and lifespan assumed in the calculation, different absolute GWP values are the result. Interesting is that the use phase of almost all studies ranges between 70% to 85% of the total GWP values, with the exception of the study by Huulgaard et al. 2013. Actually Huulgaard et al. analysed a “best case” presenting the electricity mix with a very high share of renewable energy and a “worst case” presenting the electricity mix with 100% coal-based. Even under the condition of 100% coal-based electricity, Huulgaard et al. conclude that the use and manufacturing phases still have a similar proportion with about 50%. For the EuP study it has to be noted that the production phase might be underestimated, as the MEEuP Tool was applied for modelling the production of components.

Table 17: Comparison of GWP values of televisions resulting from different studies

Source:	EuP Lot 5 (Stobbe 2007)	Andrae & Andersen 2010	EuP Lot 5 (Stobbe 2007)	Andrae & Andersen 2010	Hischier & Baudin 2010	Andrae & Andersen 2010	Huulgaard et al. 2013				EuP Lot 5 (Stobbe 2007)	Thomas et al. 2011
GWP (%)	29" CRT TV	32" CRT TV (Aoe 2003)	42" PDP TV	32" PDP TV (Aoe 2003)	42" PDP TV (value read from the figure)	32" LCD TV (Aoe 2003)	32" LCD TV (electricity mix by European suppliers)		32" LCD TV (electricity mix by 100% coal)		32" LCD TV	40" LCD TV
Life time	10a	8a	10a	8a	8a	8a	6a	10a	6a	10a	10a	7a
1. Raw materials	12%	20%	11%	29%	20%	28%	92%	80%	54%	40%	11%	23%
2. Manufacturing	3%		2%								3%	
3. Distribution/ transportation	2%		1%		2%		1%	1%	0.45%	0.34%	2%	-
4. Use phase	82%	80%	86%	71%	82%	72%	24%	34%	51%	63%	84%	77%
5. End of Life	1%	~0%	0%	~0%	-4%	~0%	-17%	-15%	-6%	-4%	0%	-
Absolut value of GWP	1191 kg	1000 kg	2678 kg	1600 kg	Not specified	1100 kg	313 kg	362 kg	1057 kg	1417kg	1281 kg	2622 kg

3.5.2 Results by Thomas et al. (2011)

Thomas et al. (2011) investigated merely the global warming potential of leading contributory gases from a 40 inch LCD TV with focus on the impacts of NF_3. Authors indicated explicitly that Hischier & Baudin (2010), which is detailed analysed in section 3.4, did not assess the impacts of NF_3 in their study. NF_3 is used in the manufacturing process of LCDs to clean the vacuum chambers and has a global warming potential being 17,000 times higher than carbon dioxide. Moreover, Thomas et al. (2011) described that NF_3 does not have a known recycling process, such as the carbon cycle for CO_2, which leads to an ever-increasing amount of NF_3 in the atmosphere. Therefore, a PCF study of a 40" LCD TV was conducted with the focus on NF_3 emissions. The amount of NF_3 produced per LCD manufacturing was determined on the basis of IPCC (the Intergovernmental Panel on Climate Change methodologies) Tier 2a method. The cradle-to-gate results (Figure 6) show that CO_2 is the leading contributor to GWP, followed by volatile organic compounds (VOCs) accounting for 9% of the contribution to GWP. NF_3 contributes 4% to GWP in the manufacturing stage.

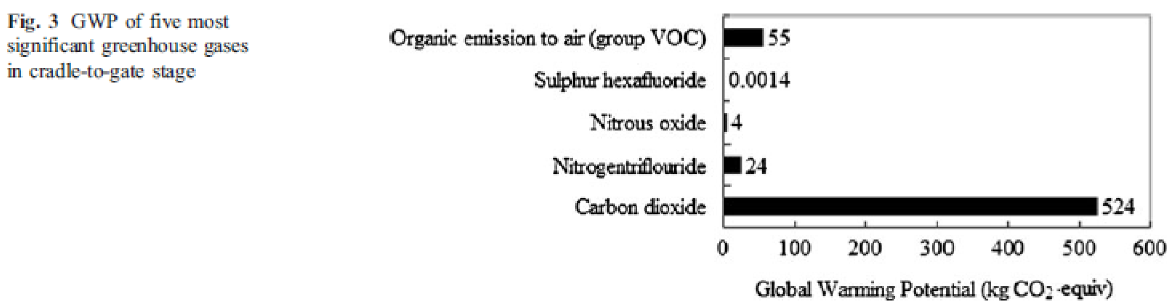

Figure 6: Main contributors to GWP in the LCD production stage (source: Thomas et. al. 2011)

In addition, Thomas et al (2011) revealed that the most significant source in the cradle-to-gate stage was the energy needed during the manufacturing process and all upstream processes. The energy supplied was assumed to be derived from a coal-powered electric plant. The second largest contributor to GWP was the production of the LCD glass panel sourcing from natural gas and the CO_2 emissions from the production of the glass fibres.

Overall, NF_3 contributes less than 1% to the total GWP within the whole life cycle phases. Authors also stressed that the result should not be interpreted to mean that the impact of NF_3 is negligible for manufacture of LCD televisions, because the assessment portfolio is dynamically changing. NF_3 can be controlled 100% by the LCD-producing industry, whereas the CO_2 emissions from energy sectors in the secondary and tertiary industry sectors might be difficult to control.

3.5.3 Results by Feng & Ma (2009)

In the study by Feng & Ma (2009), CRT TVs are the object being investigated. The CRT technology is sharply decreasing, thus it will not be further analysed. However, the result of environmental impacts will be compared to the CRT evaluated by Hischier & Baudin (2010) to examine whether the results are consistent.

Feng & Ma (2009) analysed four environmental impacts: global warming, acidification, eutrophication, photochemical ozone formation. The results are partitioned into production of manufacturing materials, transport, TV manufacturing, distribution, use, end-of-life stages. The analysis provides similar results to Hischier & Baudin (2010): manufacturing phase including production of materials and use phase are the main contributors with relative same proportion to these four impact categories.

3.6 Summary of key environmental issues identified by the LCA and further studies

- All three technologies, CRT, LCD, and PDP show a similar picture regarding the different life phases: Use and production phases have the highest environmental impacts, while distribution and EoL are of a minor importance. Within the further, non-comprehensive LCA studies, the use phase is dominating the environmental impacts over the manufacturing phase. However, as sensitivity analyses show, this relation can be switched from the use phase to the manufacturing phase when the applied electricity mix in the use phase is varied. The study by Huulgaard et al. 2013 shows the importance of the production stage, which has the highest contribution for both LCD TVs investigated.
- The overall life span has also a significant impact on use phase. The shorter the life span, the more likely it is that the dominant environmental impact shifts to the manufacturing phase.
- The environmental impact categories, especially photochemical oxidation, acidification and human toxicity in the manufacturing phase can be reduced, if EoL treatment is managed sound, so that the secondary resources from recycling can avoid primary production. Surely, it also contributes to the resource depletion.
- The use phase is very sensitive to consumer behaviour. Significant environmental benefit can be achieved from stimulating “best case” user behaviour in terms of reducing standby consumption of televisions.
- Among technologies, LCD technology shows the highest environmental impact across the entire life cycle, or an impact close to the highest impact. PDP technology shows the lowest impact, if the total score of Ecoindicator 99 is considered.

- In the study for LCD TVs, GWP and respiratory inorganics potential are the most relevant environmental hot spots within the impact categories investigated. The other 14 environmental impact categories have very low contributions.
- According to Hischier & Baudin (2010), at component level,
  - For LCD TVs, the assembly process of the LCD module as well as the used amount of chrome steel for the housing and the PWB used are the main contributors.
  - For PDP televisions, within the manufacturing phase PWB has the greatest contribution to environmental impacts, followed by the aluminium parts of the housing. The high impacts from PWB are mainly from the production process of the various electronic components (i.e. capacitors, inductors etc.), SO_2 emissions to air in the palladium production, due to nitrogen oxides to air and COD emissions from the disposal processes in the wafer production as well as the treatment of waste from the bauxite digestion. Only in case of resource depletion the PDP unit has an impact of more than 20% of the total impact due to the xenon gas in the filling.
  - For CRT televisions, the PWB and the chrome steel used in the housing are the main contributors at component level.

The following summarises concrete redesign measures obtained from the case study of Econova televisions and other conclusions concerning recommendation for ecodesign requirements, since these might be useful for the development of EU ecolabel criteria:

- To turn off the television is facilitated as the on/off-switch has been moved to the front panel, in clear view of consumers.
- Minimization of the use of aluminium by replacing the back cover by an organically shaped back plate.
- Use of high-pressure die-cast aluminium (95% post-consumer scrap and 5% primary aluminium).

- Application of a powder coating onto the die-casting that does not hinder recycling.
- The TV should be easy to disassemble.
- It is found that in the case of TVs, the implementing measures under Ecodesign requirement are not addressing the most important impacts when exclusively setting requirements to energy consumption in the use phase. The results recommend that future Ecodesign requirements shall cover more life cycle phases of the product in order to address the most import impacts.

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