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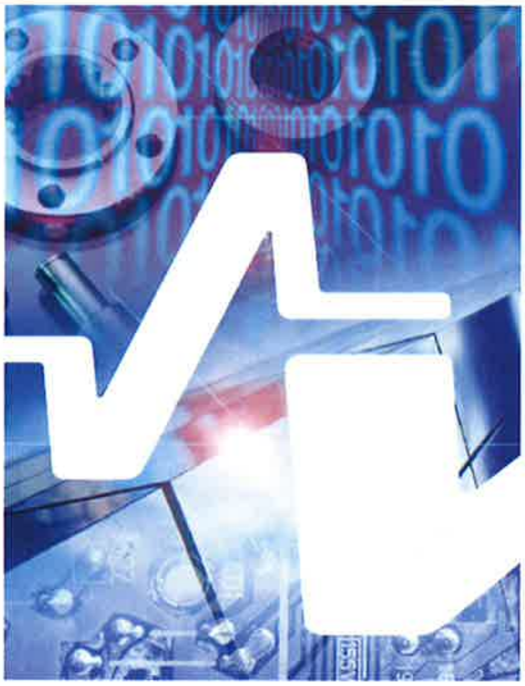

CRM_InnoNet

Internal report summarising the results of ICT and electronics sector analysis

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Summary

This report summarises the results of supply chain analysis to identify critical raw material dependence and the role of Europe in the supply chain for specific applications in ICT and electronic sector.

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Substitution of Critical Raw Materials



Deliverable report

D4.2 Internal report summarising the results of ICT and electronics sector analysis

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SEVENTH FRAMEWORK PROGRAMME

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D4.2 Internal report summarising the results of ICT and electronics sector analysis

Deliverable description

This report summarises the results of supply chain analysis to identify CRM dependence and the role of Europe in the supply chain for specific applications in ICT and electronic sector.

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Abbreviations

AMOLED	Active-matrix organic light emitting diode
AOC	Active optical cable
AZO	Aluminium doped zinc oxide
BSCCO	Bismuth strontium calcium copper oxide
CAGR	Compound annual growth rate
CCFL	Cold cathode fluorescent lamp
CRM	Critical raw material
CRT	Cathode ray tube display
CT	Computed tomography
CTV	Cable TV
DSL	Digital subscriber line
FTO	Fluorine doped tin oxide
GHG	Greenhouse gas
HB-LED	High-brightness light-emitting diode
HTS	High temperature superconductor
IC	Integrated circuit
ITO	Indium-tin oxide
LCD	Liquid crystal display
LED	Light-emitting diode
LuAG	Lutetium aluminium garnet
MEM	Microelectromechanical system
MOCVD	Metalorganic chemical vapour deposition
MRI	Magnetic resonance imaging
NdFeB magnet	Neodymium-iron-boron magnet, permanent magnet
n.e.c.	Not elsewhere classified
OEM	Original equipment manufacturer
OLED	Organic light emitting diode
OM	Optical multi-mode fibre
PCB	Printed circuit board
PDP	Plasma display panel
PEDOT:PSS	Poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate)
PGM	Platinum group metal
R&D	Research & development
REE	Rare earth element
SED	Surface-conduction electron-emitter display
SMEs	Small and medium enterprises
TAG	Terbium aluminium garnet
TCO	Transparent conducting oxide
VCR	Video cassette recorder
WEEE	Waste electronic and electrical items
wLED	White light-emitting diode
YAG	Yttrium aluminium garnet
YBCO	Yttrium barium copper oxide

Elements and compounds

Al	Aluminium
AlGaAs	Aluminium gallium arsenide
As	Arsenic
B	Boron
Be	Beryllium
Ce	Cerium
Dy	Dysprosium
Er	Erbium
Eu	Europium
Fe	Iron
Ga	Gallium
GaAs	Gallium arsenide
GaN	Gallium nitride
Gd	Gadolinium
Ge	Germanium
$GeCl_4$	Germanium tetrachloride
GeO_2	Germanium dioxide
Ho	Holmium
In	Indium
InAlAs	Indium aluminium arsenide
InGaAs	Indium gallium arsenide
Lu	Lutetium
Mg	Magnesium
MgB_2	Magnesium-diboride
MgS	Magnesium sulphide
Nb	Niobium
Nd	Neodymium
P	Phosphorus
P_2O_5	Phosphorus pentoxide
Pd	Palladium
Pr	Praseodymium
Ru	Ruthenium
Sb	Antimony
SiO_2	Silicon dioxide, silica
Ta	Tantalum
Tb	Terbium
Tm	Thulium
Y	Yttrium
Yb	Ytterbium
ZnO	Zinc oxide

1 Introduction and objectives of supply chain analysis, definition of the perimeter studied

The ICT and electronics sector provides products and services both for consumers, industries and professional users. Because the focus of the study is critical raw materials (CRM), services were excluded. The ICT and electronic sector's products may be used in various sectors as end applications or as components. Therefore, in order to clarify the produced products, a rough categorization between applications can be perceived:

- Products which capture, transmit and display data and information electronically, such as computers, phones, displays and other communication equipment, consumer electronics
- Lighting
- Domestic appliances
- Professional applications, such as medical applications, control equipment, sensors, tools
- Electronic sub-components which are used in different applications e.g. printed circuit boards.

Rapid changes, due to the relatively short lifetimes of the products are characteristic for the ICT and electronics sector. Because of small size and low transport costs, the production and assembly of components and most of the ICT consumer products can be quite easily moved to the countries with lower production costs.

The objective of this study is to identify applications in the ICT and electronics sector which are CRM dependent and are important to the European economy. When starting the work, the objective was to make a value chain analysis of selected applications. However, it was found that using the data sources available, it was not possible to get information on the value addition of components used in the end applications, which is required for a full value chain analysis. Therefore it was chosen to rather make an analysis of the supply-chains as a way to get at least partial information on the value chain.

The specific application supply chains analyses carried out as a part of this study helps detect possible bottlenecks within the supply chain and identify Europe's role throughout the chain. As a result, a better sense of potential CRM supply risk to European industry will be achieved. This in turn will help to identify those areas where substitution may be one of the options to mitigate these risks.

This analysis of the ICT and electronics sector will be complemented by similar analysis for the Energy and Transport sectors. In combination with bottom-up analysis of CRM applications, these reports will provide the background information required for prioritizing domains for substitution road mapping.

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Substitution of Critical Raw Materials

2 Supply chain analysis methodology

In order to have a unified and transparent approach for selection of applications for supply chain analysis and to enable direct comparison of the applications chosen, a common methodology was developed and applied for the three sectors studied. The scheme of the application selection for the supply chain analysis is presented in Figure 1.

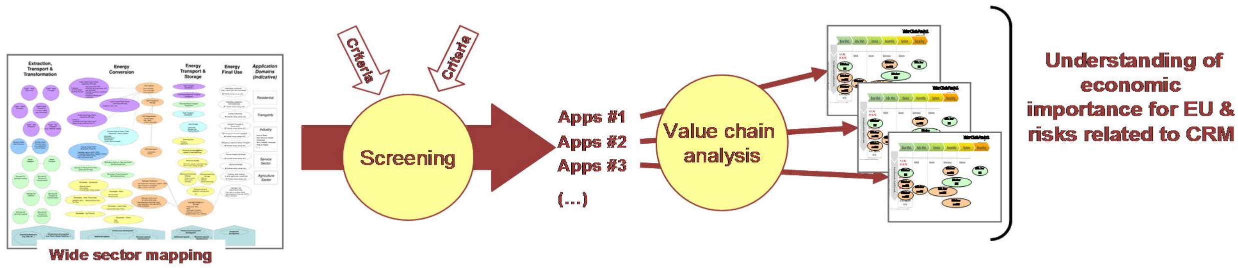


Figure 1: Approach to selection of applications for supply chain analysis.

The selection process of applications for the supply chain analysis is divided in two steps. In the first step the number of applications was reduced to approximately five applications. The second step comprised of supply chain analyses including statistical analysis and examination of market and technical quantitative and qualitative data by experts. A more detailed description of the methodology applied in supply chain analysis is described in Appendix 1.

3 Screening of applications for supply chain analysis

Critical raw materials are widely used and vital to the function of many different applications in the ICT and electronics sector. Therefore, reducing the number of applications and highlighting the most important applications for the European economy is required.

3.1 Identification of CRM dependencies

Applications from the ICT and electronics sector have been listed for identification of CRM dependencies. The key CRM required for the functioning of the applications have been identified. Table 1 presents a summary of all applications with possible CRM.

Table 1: Summary of CRM dependencies and identification of applications which will be further considered for analysis.

Application	CRM-Use (EU-14 CRM)	Comment	Progress to evaluation of economic importance
Washing machines	Nd, Dy	Including drying machines.	Yes
Dishwashers	Nd, Dy		Yes
Cooling appliances	Nd, Dy		Yes
Air conditioners	Nd, Dy		Yes
Vacuum cleaners	No material	Some vacuum cleaners may contain CRM in motors and assembled PCB, however specific information does not exist.	No
Food mixers	No material	Some food mixers may contain CRM in motors and assembled printed circuit boards, however specific information do not exist.	No
Computer PCs (desktop)	Many CRM	Quantity and production of desktops are decreasing due to increased use of laptops and therefore desktops were not selected for further study.	No
Laptops	Many CRM	Includes also notepads.	Yes
Printers, copying machines	Nd, Dy	Since electric interaction is replacing printers, printers were not selected for further study.	No
Mobile (Smart) phones	Many CRM		Yes
Optical fibres	Ge		Yes
Display and screens	Many CRM		Yes
Video cameras	Many CRM		Yes
Cameras	Many CRM		Yes
Radio sets	Many CRM		Yes
Loudspeakers	Nd, Dy		Yes
Fluorescent lamps	Many CRM	LED lighting is replacing fluorescent lighting and therefore fluorescent lamps were not selected for further study.	No
LED lighting	Many CRM	Whole lighting systems, not only LED dies.	Yes
Electric tools (cordless)	Nd, Dy		Yes
Magnetic resonance imaging (MRI)	Many CRM	X-ray applications may contain CRM in films, however specific information in x-ray apparatus do not exist and therefore MRI represents the medical imaging application	Yes

3.2 Preliminary evaluation of European economic importance

In the examination of European economic importance, information from Eurostat's PRODCOM database (Eurostat 2010a) has been used. The applications identified above were 'matched' with the most relevant group/product according to PRODCOM's classification system. In some cases, there is not an obvious match and an application might be spread across many several PRODCOM groups. Where multiple PRODCOM groups are relevant to a particular application, those groups are aggregated. For example optical fibre includes two PRODCOM groups: *Optical fibre cables made up of individually sheathed fibres whether or not assembled with electric conductors or fitted with connectors and Optical fibres and optical fibre bundles; optical fibre cables (except those made up of individually sheathed fibres)*. The corresponding PRODCOM group(s) for the selected applications are presented in Table 2.

Table 2: Corresponding PRODCOM group(s) for the applications selected for European economic evaluation.

Application	Corresponding PRODCOM group (including code)
Washing machines	27511300 - Cloth washing and drying machines, of the household type
Dishwashers	27511200 - Household dishwashing machines
Cooling appliances	27511110 - Combined refrigerators-freezers, with separate external doors 27511133 - Household-type refrigerators (including compression-type, electrical absorption-type) (excluding built-in)
Air conditioners	28251220 - Window or wall air conditioning systems, self-contained or split-systems 28251250 - Air conditioning machines with refrigeration unit (excluding those used in motor vehicles, self-contained or split-systems machines)
Laptops	26201100 - Laptop PCs and palm-top organisers
Mobile (Smart) phones	26302200 - Telephones for cellular networks or for other wireless networks
Optical fibres	27311100 - Optical fibre cables made up of individually sheathed fibres whether or not assembled with electric conductors or fitted with connectors 27311200 - Optical fibres and optical fibre bundles; optical fibre cables (except those made up of individually sheathed fibres)
Display and screens	26201700 - Monitors and projectors, principally used in an automatic data processing system 26402020 - Tuner blocks for CTV/VCR and cable TV receiver units (colour video tuners) (excluding those which isolate high-frequency television signals) 26402040 - Colour television projection equipment 26402090 - Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c. 26403460 - Flat panel video monitor LCD or plasma , etc. without tuner (colour video monitors) (excluding cathode-ray tube) 27902020 - Indicator panels incorporating liquid crystal display (LCD) 27902050 - Indicator panels incorporating light emitting diodes (LED) 27902080 - Electrical apparatus for sound or visual signalling, n.e.c.
Video cameras	26403300 - Video camera recorders
Cameras	26701300 - Digital cameras
Radio sets	26401100 - Radio broadcast receivers (except for cars), capable of operating without an external source of power
Loudspeakers	26404235 - Single loudspeakers mounted in their enclosures (including frames or cabinets mainly designed for mounting loudspeakers) 26404237 - Multiple loudspeakers mounted in the same enclosure (including frames or cabinets mainly designed for mounting loudspeakers)
LED lighting	27403200 - Lighting sets for Christmas trees 27403300 - Searchlights and spotlights (including for stage sets, photographic or film studios) 27403910 - Electrical lighting or visual signalling equipment for motor vehicles (excluding electric filament or discharge lamps, sealed beam lamp units, ultraviolet, infrared and arc lamps) 27907010 - Electrical signalling, safety or traffic control equipment for railways or tramways 27907030 - Electrical signalling, safety or traffic control equipment for roads, inland waterways, parking facilities, port installations or airfields
Electric tools (cordless)	28241113 - Electro-mechanical hand drills operated without an external source of power 28241120 - Electro-mechanical hand tools operated without an external source of power (excluding drills, saws)
MRIs	26601115 - Apparatus based on the use of X-rays, for medical, surgical, dental or veterinary uses (including radiography and radiotherapy apparatus)

3.3 Selection of applications for CRM supply chain analysis

The data from PRODCOM were extracted and analysed for each application in order to address whether criteria presented in Appendix 1 are met.

The economic importance of selected applications is presented in Table 3.

Table 3: Selection of applications for CRM supply chain analysis. Data from 2012, except sector values from 2011.

Sector and its production value (2011)	Application	CRM-Use (EU-14 CRM)	EU economic importance			Progress to full supply chain analysis
			Value (2012) in € million	Share of prod. >25%	Share of products in sector >0.2%	
Manufacture of electrical equipment €270,000 M	Washing machines	Nd, Dy	4,600	82%	1.7%	Yes
	Dishwasher	Nd, Dy	2,200	85%	0.8%	No*
	Cooling appliances	Nd, Dy	2,400	59%	0.9%	No*
	Air conditioners	Nd, Dy	2,800	63%	0.5%	No*
	Optical fibres	Ge	1,400	69%	0.5%	Yes
	Displays and screens	Ce, Er, Eu, Ga, Ge, Gd, In, La, Nd, Pd, Pr, Ru, Ta, Tb, Tm, Sb, Y	15,200	63%	5.6%	Yes
	LED lighting	Ce, Eu, Ga, Gd, Ho, In, La, Ta, Tb, Tm, Sb, Y	7,300	79 %	2.7%	Yes
Manufacture of computer, electronic and optical products €260,000 M	Laptops	Br, Dy, Eu, Ga, Ge, Gd, In, La, Nd, Pd, Pt, Pr, Rh, Ru, Ta, Sb, Y	2,300	8%		No
	Mobile (Smart) phones	Br, Dy, Eu, Ga, Ge, Gd, In, La, Nd, Pd, Pt, Pr, Rh, Ru, Ta, Sb, Y	3,000	10%		No
	Video cameras	Ce, Er, Eu, Ga, Ge, Gd, In, La, Nd, Pd, Pr, Ru, Ta, Tb, Tm, Sb, Y	320	17%		No
	Cameras	Ce, Er, Eu, Ga, Ge, Gd, In, La, Nd, Pd, Pr, Ru, Ta, Tb, Tm, Sb, Y	320	8%		No
	Radio sets	Ga, Ge, Nd, Pd, Pr, Ru, Ta, Sb	170	14%		No
	Loudspeakers	Nd, Dy	450	59%	0.18%	No
	MRIs	Dy, Gd, Nb, Nd, Pr, Tb	3,300	81%	1.3%	Yes
Manufacture of machinery and equipment n.e.c sector €550,000 M	Electric tools (cordless)	Nd, Dy	240	27%	0.04%	No

*All large household appliances (washing machines, dishwashers, cooling appliances and air conditioners) include generator/compressors/electric motors which may contain NdFeB magnets. Due to the similarities between all major appliances washing machine will be handled as a case example since it had the largest production in Europe.

Based on the economic screening of the applications presented in Table 3, five applications were selected for supply chain analysis. These applications are:

- Magnetic resonance imaging
- LED lighting
- Optical fibre
- Display and screens
- Washing machines

In addition to the applications that were selected for the supply chain analysis, assembled printed circuit boards (assembled PCB) will be analysed due to their presence in almost every application in all three sectors (Electronic & ICT, Energy and Transport). The assembled PCB is a crucial component in wide range of applications providing energy and functionality to the application.

4 Supply chain analysis of applications

4.1 Magnetic resonance imaging apparatus (MRI)

4.1.1 MRI technologies and CRM dependence

Magnetic resonance imaging (MRI) is a medical imaging technique used for visualising the internal morphology of the body. MRI enables imaging of soft tissues and organs in such a great contrast that the technique is especially suitable for neurological, cardiovascular, musculoskeletal, as well as oncological imaging. MRI is based on a nuclear magnetic resonance (NMR) and measures a radio frequency signal emitted by the nucleus of hydrogen atoms in a magnetic field. An MRI system includes magnets, a pulsed field gradient system, radio-frequency (RF) transmit coils, transmitters, a radio-frequency receiver and a computer system (Fishbein *et al*. 2005).

Critical raw materials in an MRI system are found in the magnet unit, spring contacts, cold heat, pole-piece computer display and printed circuit boards. There are three alternative magnetic resonance imaging technologies based on three different types of magnets used in the MRI systems; permanent, resistive and superconducting. The CRMs in the permanent and superconductive magnets are discussed in this analysis. MRI systems that contain resistive magnets have a minor role in the magnetic resonance imaging market due to their limited field strength, high energy consumption and cooling system dependence, and are excluded from the analysis. A superconducting electromagnet is the most frequently used magnet in the MRI system, accounting for more than 75% of MRI equipment installed. Almost all MRI systems with a central field strength of more than 0.35 tesla use superconducting coils. (Cosmus & Parizh 2011.)

A structural composition of MRI application presented in Table 4.

Table 4: Structural composition of MRI system.

Magnetic resonance imaging (MRI)	CRM content	Comments
Magnet unit (permanent or superconductive magnet)		
Permanet magnet		
Iron boron magnets, NdFeB	Nd, Dy, Pr, Tb	NdFeB magnet contains also small ammount of Dy, Pr and Tb
Gradient coils		
Radiofrequency coils		
Electric motors		
Permanent magnet		Different kinds of motors are used to move units/parts
Iron boron magnets, NdFeB	Nd, Dy, Pr, Tb	
Superconducting magnet	Nb	
Pole-piece	Ho	
Spring contacts	Be	
Cold heat	Ho	
Printed circuit board (with components)		
Printed circuit board (bare without components)		
Plating	Pd	Not very common to use Pd as plating, generally Ni/Cu and Au are used
Components		
Capacitors	Ta, Pd, Nb	
Resistors	Ru, Ta	
Semiconductors	Ga, Ge, In, Sb	
Transistors	Ga, Ge	
Electronic and integrated circuits		
Capacitors	Ta, Pd, Nb	
Resistors	Ta, Ru	
Semiconductors	Ga, Ge, In, Sb	
Transistors	Ga, Ge	
Connectors	Pd, Ru, Be	
Cables		
Display		
LCD display		
Housing		
Frame		
LCD module		
Glass substrate		
Liquid crystal		
Conductive electrodes		
ITO	In	
Orientation films		
Color filter		
Films		
Backlight		Backlight can be produced either by fluorescent tubes or LED
Fluorescent tube		
Luminescent powder	Ce, Y, Tb, Lu, Eu, Gd	
LED		
Semiconductor die	In, Ga	
Luminescent powder	Ce, Y, Tb, Lu, Eu, Gd	

Niobium (Nb) alloys and chemicals are used in the manufacture of superconducting magnet based MRI systems. In the production of these magnets, for example niobium-titanium, niobium-tin and niobium nitrite are used. (Moreno 2011.) Niobium-titanium and niobium-tin are used for making coil windings for superconducting magnets, and can be fabricated into superconducting wires. The majority of superconductive materials produced in the world are destined for use in MRI systems. About 60% of all superconducting wire and about 40% of niobium-tin alloy produced are consumed by MRI magnet manufacturing. (Marken 2004, cited by Cosmus & Parizh 2011.) However, the MRI industry uses only few percent of the total amount of niobium produced annually (NioCorp Developments Ltd. 2013).

Based on the company interviews, in addition to niobium the following materials from the EU-list have been identified as critical for the production of MRI systems, due to their irreplaceable functionalities (CRM_InnoNet 2013a):

- Beryllium (Be) has certain mechanical qualities combined with electric qualities, which makes it especially usable in spring contacts (in a form of beryllium-copper), for shielding the magnet and to obtain a durable, solid resolution (other materials would break) (CRM_InnoNet 2013a).
- Holmium (Ho) is used in high field MRI systems; it is an important component of the cold head and operates as a helium-liquefier to prevent evaporation of He and enables helium reuse (CRM_InnoNet 2013a). Holmium can also be used for the pole-pieces of MRI systems (KU Leuven 2012). A pole-piece is added on the magnetic pole for producing a high homogenous magnetic field, however, also other materials can be used (Wu *et al.* 2010).

Permanent magnets are large and heavy, and thus their use is usually limited to systems operating with maximum field strength of 0.4 tesla in magnetic resonance imaging (Lazar 2012). The most common type of permanent magnet used is so-called NdFeB magnet; neodymium (Nd), iron (Fe) and boron (B) containing magnet, with the formula $Nd_2Fe_{14}B$. NdFeB magnets also contain a small amount of dysprosium (Dy), praseodymium (Pr) and terbium (Tb). The magnet consists around 67.4 – 72.8% iron, 26.7 – 31.6% REEs and 1% boron (Peiró *et al.* 2013a). The average percent by weight REE consumption distribution of magnets is 69.4% neodymium, 23.4% praseodymium, 5% dysprosium, 2% gadolinium (Gd) and 0.2% terbium (Figure 2) (Morgan 2010).

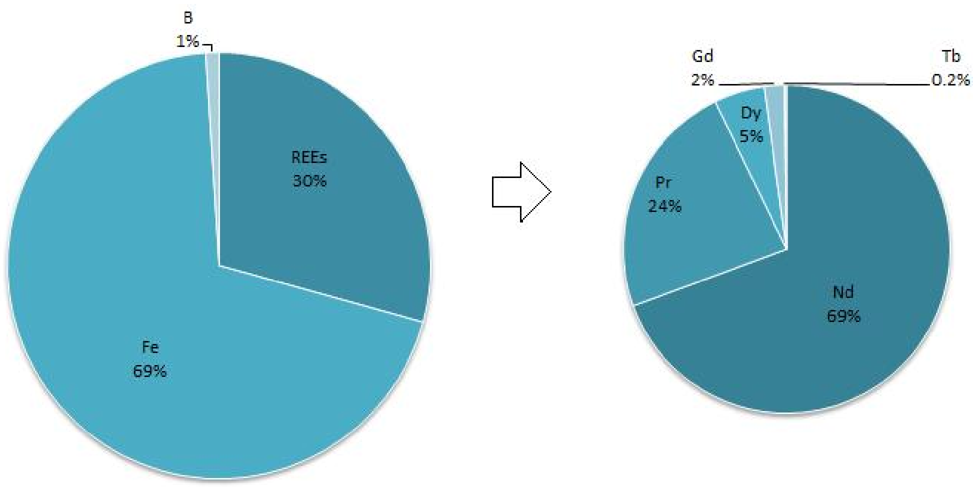


Figure 2: The average composition of permanent magnet (Morgan *et al.* 2010, Peiró *et al.* 2013a).

Around 21% of the total rare earth consumption, corresponding to 24,063 tons of rare earth metals was used for producing permanent magnets in 2010, consisting of 16,700 tons of Nd; 5,631 tons of Pr; 1,203 tons of Dy; 481 tons of Gd; and 48 tons of Tb. Around 98% of these amounts were used for NdFeB magnet production. (Peiró *et al.* 2013a.) In 2012, the rare earth demand for permanent magnets was estimated to be around 25,500 tons (Shaw & Constantinides 2012). Based on different studies, Peiró *et al.* (2013a) estimated the average total amount of the rare earths per MRI unit to be around 860 kg of NdFeB magnets. According to them, the calculated overall amount of each metal used in the NdFeB magnets for MRI systems was 450 tons of Nd, 155 tons of Pr, 35 tons of Dy, and 4-5 tons of Tb in 2010, accounting for the total amount of approximately 645 tons. Also around 90 tons of gadolinium is used in the magnetic resonance imaging annually. However, Gd is used as a contrast medium in the patient examinations, not in the actual magnet production process. (Peiró *et al.* 2013a-b.)

In addition, various electric motors are needed to move units or parts in the MRI systems, and these motors may involve NdFeB magnets too due to their small size. However, they are not the most essential components in terms of substitution. Various components of the computer unit controlling the MRI system, such as printed circuit boards and the display also contain critical raw materials. A detailed analysis of displays is presented in section 4.4. and the analysis of printed circuit boards in section 4.6. LEDs are components found in multiple technologies and are also analysed separately in detail (see section 4.2).

4.1.2 Analysis of CRM-related MRI market and supply chain

Economics

Global markets for superconducting and permanent magnets

The global superconducting magnet market is predicted to grow to \$2.94 billion (€2.20 billion) by 2017 (Global Industry Analysts 2011). According to another more moderate forecast by BCC Research (2012a), the market for superconducting magnets was around \$1.8 billion (€1.33 billion) in 2012 and is estimated to grow to around \$2.3 billion (€1.70 billion) in 2017.

The present market for NdFeB magnets can be divided as follows: around 72% of the magnets produced are used in electrical and electronic devices (hard drives, microphones and loudspeakers), 20% in electric vehicles, 5% in wind turbines, and 3% in MRI scanners (Peiró *et al.* 2013a). Constantinides (2012) analysed, based on the results by Benecki *et al.* (2010), the transparent (readily available) market data for the overall permanent magnet markets (excluding Russia, much of India and also some of the Chinese domestic markets). According to their analysis, sales in dollars are increasing and NdFeB magnets, which currently have the highest sales shares, exhibit also the strongest growth estimate, accounting for sales of around \$15 billion (€11 billion) in 2015 and \$17 billion (almost €13 billion) by 2020. In 2007, the vast majority of NdFeB magnet manufacturing sites were located in Asia, mainly in China and Japan, with Europe having only around 2% share of global production. (Du & Graedel 2011.) The current situation is almost the same as in 2007; China produces around 80% of permanent magnets, Japan around 17% and Europe around 3%. Overall, China has lower costs of doing business and so the product sale prices are cheaper than other competing countries are able to achieve. (Constantinides 2012.) China is forecast to maintain its leading position in the NdFeB magnet production (Benecki *et al.* 2010, cited by Shaw & Constantinides 2012).

Global and European MRI markets

MRI systems are one of the primary market areas for the medical imaging industry (Frost & Sullivan 2009a). Currently, the global annual production of MRI units exceeds 2,000 units, and it is expected that demand will continue to grow in the coming years. North America is the biggest market area at the moment, followed by Europe, but Asia is expected to have the biggest growth potential in the future, particularly in high population countries such as China and India. (Research and Markets 2013.) In 2011, the market share of the MRI systems in relation to revenues of the total medical imaging markets was around 27% in

Europe, and it is predicted that the share will remain quite constant at least until the year 2018 (Frost & Sullivan 2012a).

Based on a market analysis by Frost & Sullivan (2009), the market situation in Europe differs substantially from region to region. In 2008, the total European MRI market revenue was around $858 million (around €642 million), from which almost 92% came from Western Europe and only around 8% from Eastern Europe. However, Eastern European markets are considered to have more potential for growth than Western European markets in the future. (Frost & Sullivan 2009a.) Based on the data from Eurostat's centralized PRODCOM data base the production in EU as a value for *Apparatus based on the use of X-rays, for medical, surgical, dental or veterinary uses (including radiography and radiotherapy apparatus)* group which contains MRI applications was approximately €3.3 billion in 2012. In addition, import to EU and export from EU for the same product group was approximately €0.8 and €3.4 billion respectively. (Eurostat 2012.)

The MRI market represents a highly competitive market segment in Europe, driven by high pricing pressure. In 2011, the market revenue for the MRI systems market in Europe was $886.4 million (€668.5 million) and the revenue of the market is expected to achieve $1,233.8 million (€930.5 million) by 2018. Germany has the largest forecasted percent revenue of the MRI market between 2011 and 2018, with a share of more than 25%, followed by the United Kingdom (around 16-17%) and Italy (around 15-16%). The average selling price per system varies between $0.8 (a low field system) and $2 million (an ultra-high field system) (€0.6 and €1.5 million, respectively). Required system replacements are likely to escalate the MRI markets in the short term. Around 33% of MRI systems in Western Europe are six to ten years old, and for example in Germany and Italy around 16% exceeds a ten years of operating life. The regional segmentation of the markets is presented in Table 5. (Frost & Sullivan 2012a.)

Table 5: The European MRI market revenue forecast by region (in $ million), between 2011 and 2018 (Frost & Sullivan 2012a, modified).

Year	The United Kingdom	Germany	France	Italy	Spain	Scandinavia	Benelux	Total
2011	140.1	237.3	115.4	129.0	92.0	89.9	82.7	886.4
2012	148.3	244.7	119.7	136.1	95.7	94.0	86.7	925.2
2013	157.2	252.8	124.3	143.8	99.8	98.6	91.0	967.5
2014	166.6	260.8	129.2	152.0	104.1	103.4	95.6	1011.7
2015	176.7	269.4	134.4	160.9	108.7	108.6	100.5	1059.2
2016	188.1	290.3	139.6	176.2	113.4	113.9	105.6	1127.1
2017	199.2	301.6	144.9	186.1	118.1	118.6	110.7	1179.2
2018	210.8	313.7	150.3	196.7	123.0	123.3	116.1	1233.8

The low field systems (including the permanent magnet and resistive magnet MRIs) contribute just over 10% of sales in the European MRI markets. (Figure 3) The high and ultra-high field markets (the superconducting magnet MRIs) are expected to grow by 2018, while among the low field systems the market situation will remain almost invariable. (Frost & Sullivan 2012a.)

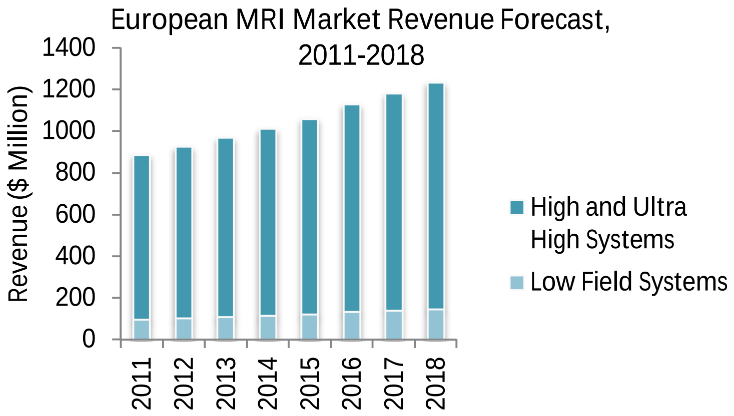


Figure 3: A revenue forecast by MRI market in Europe, between 2011 and 2018 (in $ million) (Frost & Sullivan 2012a, modified).

The fast pace of technological development in the magnetic resonance imaging industry negatively affects sales of earlier systems. An average service life of an MRI system varies between six to eight years. However, there is always some shorter-term upgrading to better technologies seen when newer applications of greater field strength systems appear on the markets. The high field systems (1.5 tesla) have the largest market share, and the market is forecasted to have a remarkable growth rate within the next two years. The market for the ultra-high systems (>1.5 tesla) is predicted to have a slower growth rate, while the market situation for the low field systems (<1 tesla), including the permanent magnet systems, is expected to remain modest towards 2018. However, some increase in demand of the low field dedicated musculoskeletal systems is assumed to come from the private sector side. (Frost & Sullivan 2012a.)

Technological advancements, newer applications and new niche clinical areas are providing growth opportunities for the MRI markets in Europe. On the other hand, the very limited reimbursement for imaging procedures in Europe, budgetary constraints and various regulatory issues are retarding the market growth. (Frost & Sullivan 2012a.)

Position of EU in supply chain and main actors

The supply chain of MRI application consists of several steps. In addition, supply chain can include parallel streams for different components including CRM. Figure 4 shows the supply chain of MRI. The supply chain is focused on superconducting and permanent magnet components other components including CRM are presented later in Figure 6.

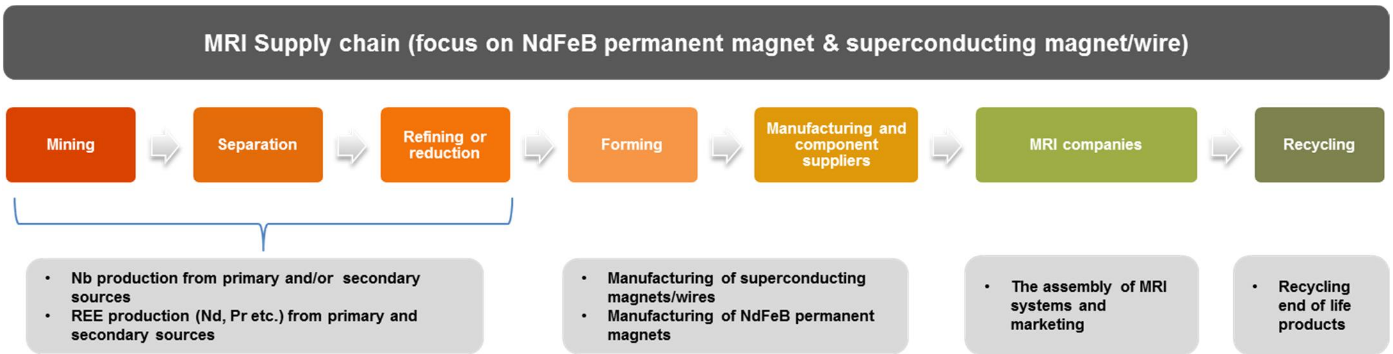


Figure 4: MRI supply chain focused on superconducting and permanent magnets.

The supply chain can be roughly divided to four different stages. The first stage is raw material production from primary or secondary sources. The material can be in the form of pure metal powder or alloy. The second stage is the manufacturing of superconducting or NdFeB magnets. At this stage the component manufacturers produce magnets for different target applications. Quality and characteristic requirements for the magnet vary based on the target application. The third stage of the supply chain is the assembly of the components to produce a comprehensive MRI system which can be marketed and sold. The final stage of the supply chain is the recycling of end of life products.

Three major MRI system manufacturers GE Healthcare, Siemens Medical Solutions and Philips Healthcare also have their own superconducting MRI magnet production. Their legacy magnet factories in the United States and Europe produce magnets for their major systems. Mitsubishi is the only independent major magnet manufacturer, which does not produce tailor made solutions. (Magnetica 2011.) Luvata, Oxford Instruments and Scientific Magnets are important overall superconducting wire/magnet producers in Europe. Luvata, for example, supplies superconductors to Philips, Siemens, GE and Mitsubishi (Luvata 2011).

Almost all permanent magnets are produced in China. Currently, there are only a few facilities for the refining of intermediate products (alloys) and final permanent magnet producers located in Europe. European companies are mostly focused on manufacturing semi-finished or finished products that contain permanent magnets. (Schüler *et al.* 2011.)

Most of the companies operating in the MRI field are small (Frost & Sullivan 2009b), but the overall markets are dominated by a few major companies. The market share of these top three competitors, Siemens, GE Healthcare, and Philips, exceeds 70% (Frost & Sullivan 2012a) and they are expected to remain as market leaders for Europe in the future. Philips Healthcare and Siemens Healthcare are European based companies, thus having a home advantage in the very price competitive markets. It is seen to be difficult even for the big global companies to challenge them in their home field, much less the smaller ones. This situation may also generate a barrier for new competitors to join the market. (Frost & Sullivan 2009b.) The number of companies in the European MRI market was more than six in 2011. The major MRI market participants in Europe and their market shares were:

- Siemens Medical Solutions, 28.6%
- GE Healthcare, 23.3%
- Philips Healthcare, 19.3%
- Toshiba Medical Systems Corp., 7.4%
- Hitachi Medical Systems, 4.6%
- Esaote SPA, 1.7%
- Others, 15.1%. (Frost & Sullivan 2012a.)

The overall market share of the six biggest competitors accounted for around 85% of the European market (Frost & Sullivan 2012a). The five major participants also dominate the global MRI market. The rest of the global market is shared by smaller companies, often directed to niche areas; e.g. Esaote focusing on low field extremity, IMRIS on intra-operative systems and Fonar on low field upright systems. Major market participants tend not to operate initially in new niche markets. No Chinese or Indian MRI producers have entered the superconducting MRI market yet, but there are a number of companies probably coming to markets in the future. (Magnetica 2011.)

In Figure 5 companies related to MRI superconducting and permanent magnet supply chains are presented.

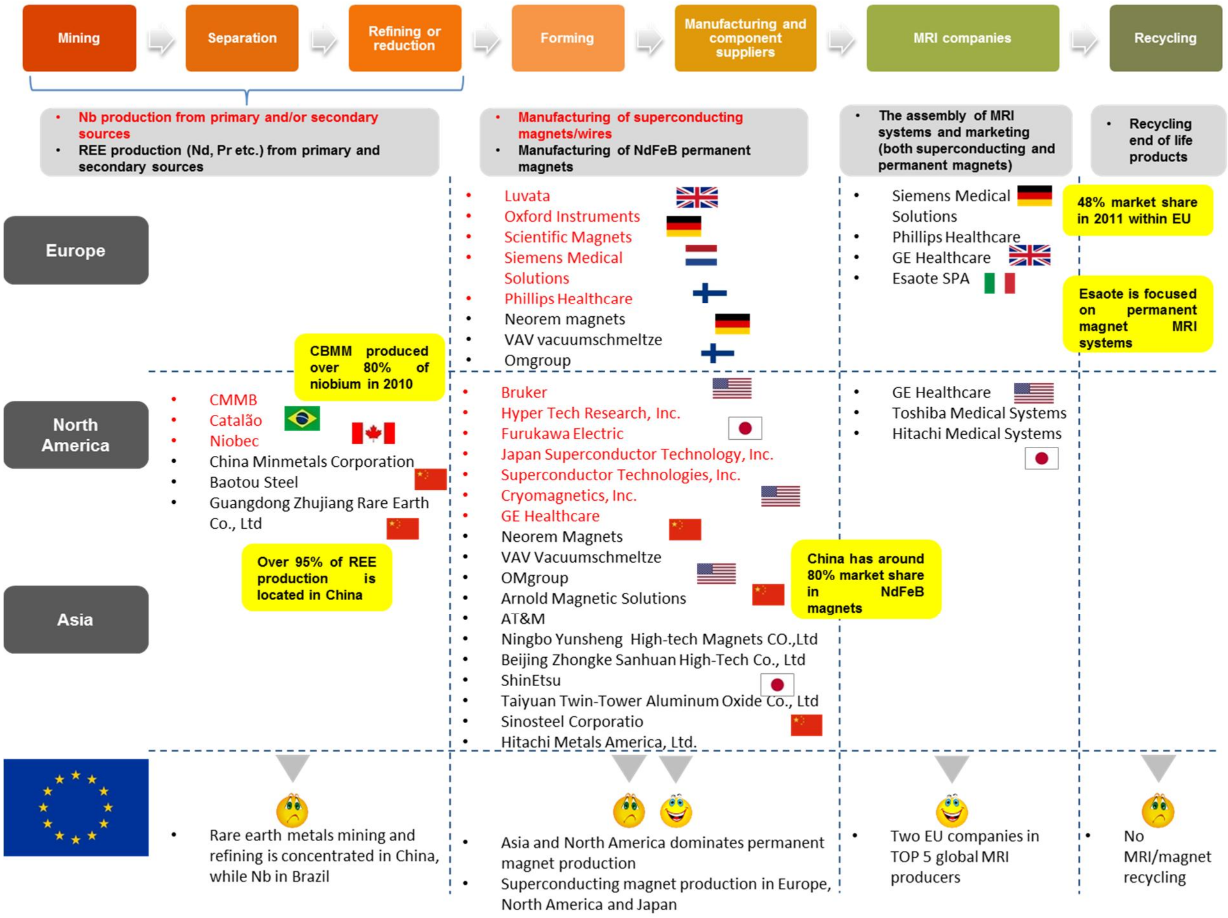


Figure 5: A summary of companies in MRI superconducting and permanent magnet supply chain. The companies marked in red present manufacturers in superconducting magnet supply chain.

Jobs involved in EU

Based on Eurostat's structural business statistics, the manufacturing of irradiation, electro medical and electrotherapeutic equipment sector employed 47,000 people in 2010 within the EU. The largest employing countries were Italy and Germany providing employment for over 10,000 people respectively. In addition, the manufacturing of medical and dental instruments and supplies sector employed over 425,000 people in 2010 within EU. Germany employed nearly 170,000 people while the next largest employing countries were France, Italy and the United Kingdom providing employment for approximately 40,000 people respectively. (Eurostat 2010b.) However, direct employment of MRI production is less than reported above. Assuming the share of direct MRI employees in the manufacturing of irradiation, electro medical and electrotherapeutic equipment sector is the same as the share of European MRI production from all medical imaging production which is around 21%, the direct employment would be approximately 10,000 people.

EUROSTAT data interpretation

The quantitative supply chain analysis was carried out on data from Europe's PRODCOM database. More detailed information on the data and application composition can be found in Appendix 2 (MRI data). The data from PRODCOM has been applied to produce a supply chain illustration for production with largest producing countries in Europe (Figure 6). **However, it is essential to understand that the shares/dimensions of different industries (box sizes) represent the production for the whole industry not only the share which is used in MRI production**.

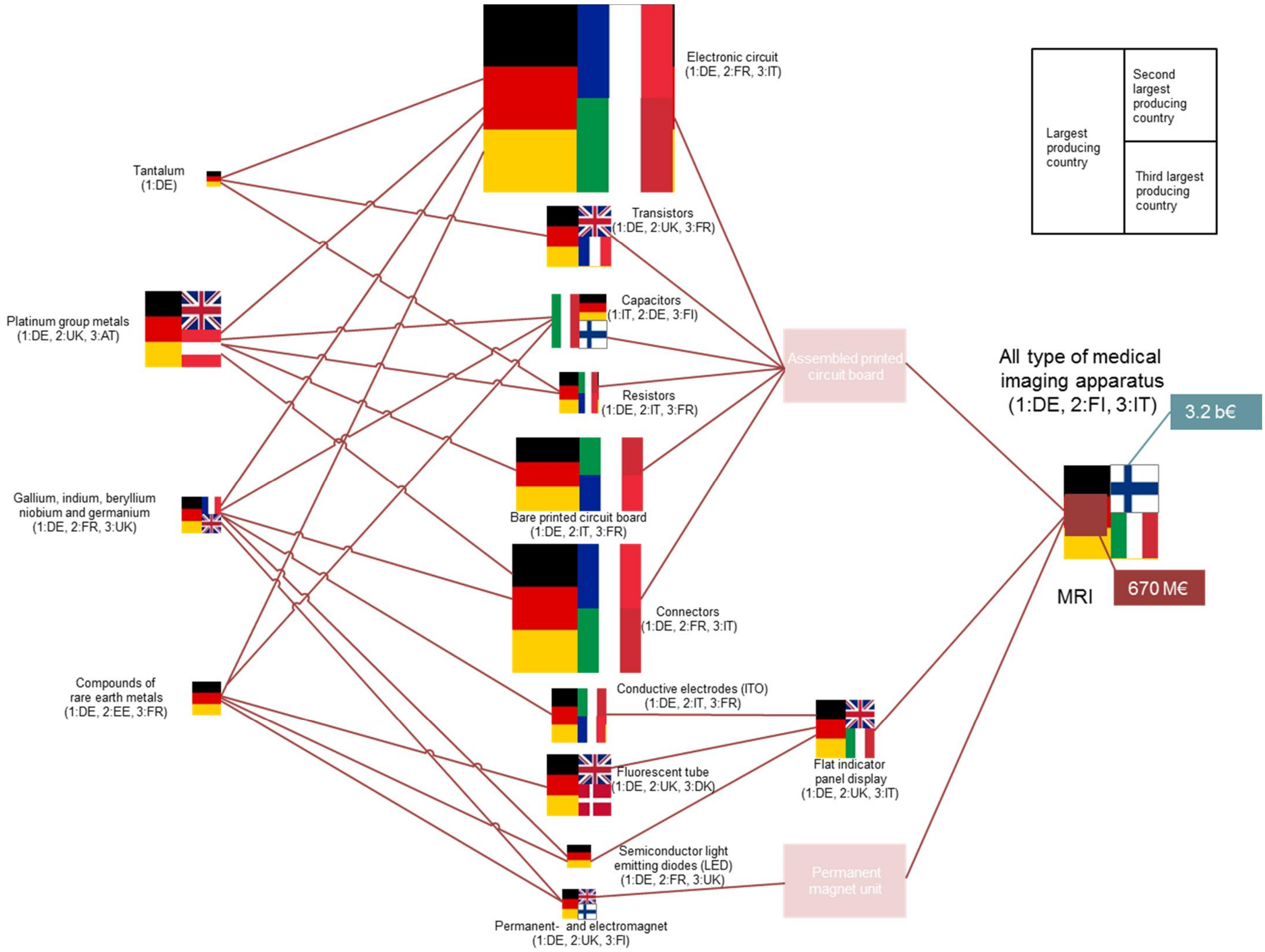


Figure 6: EU production of MRI systems and related (sub)-components and materials. (Sub)-components in pink boxes have no corresponding PRODCOM group and therefore no statistically defined value and are included for completeness. The green box represents the total value for all medical imaging equipment and therefore red box inset presents the value of MRI production based on data from a market report by Frost and Sullivan (2012a). Each box presents the total production value, not the value of components/materials which are used only in MRI applications. In addition, the largest EU producing countries are presented.

Examining the PRODCOM data in Figure 6 it can be noticed that in the supply chain of MRI the production exists both on component and end application level. Especially electrical components' production value is significant. However, it should be noticed that these components are also used in other applications not only in MRI. In turn, magnet production is significantly less than other component production. In addition, this group contains all kind of magnets not only permanent or superconducting magnets which decreases the production of these "critical" magnets even more. As for the end application the whole medical imaging equipment production is a strong business area from which MRI composes approximately 20% ending to a value of €670 million.

The production in the supply chain of MRI is concentrated to Central Europe, Germany as the largest producing country in almost every step in the chain. Companies such as Siemens Medical Solutions and GE Healthcare have MRI production facilities in Germany. In addition, Siemens Medical Solutions has superconducting magnet production in the UK. Other large producing countries were Italy, France and the UK. Both France and Italy are focused more on component and end application (Italy) production, while the UK concentrate on component and material production. In addition, Finland has both end application and component production.

The balance between production, import and export values within MRI supply chain is presented in Figure 7.

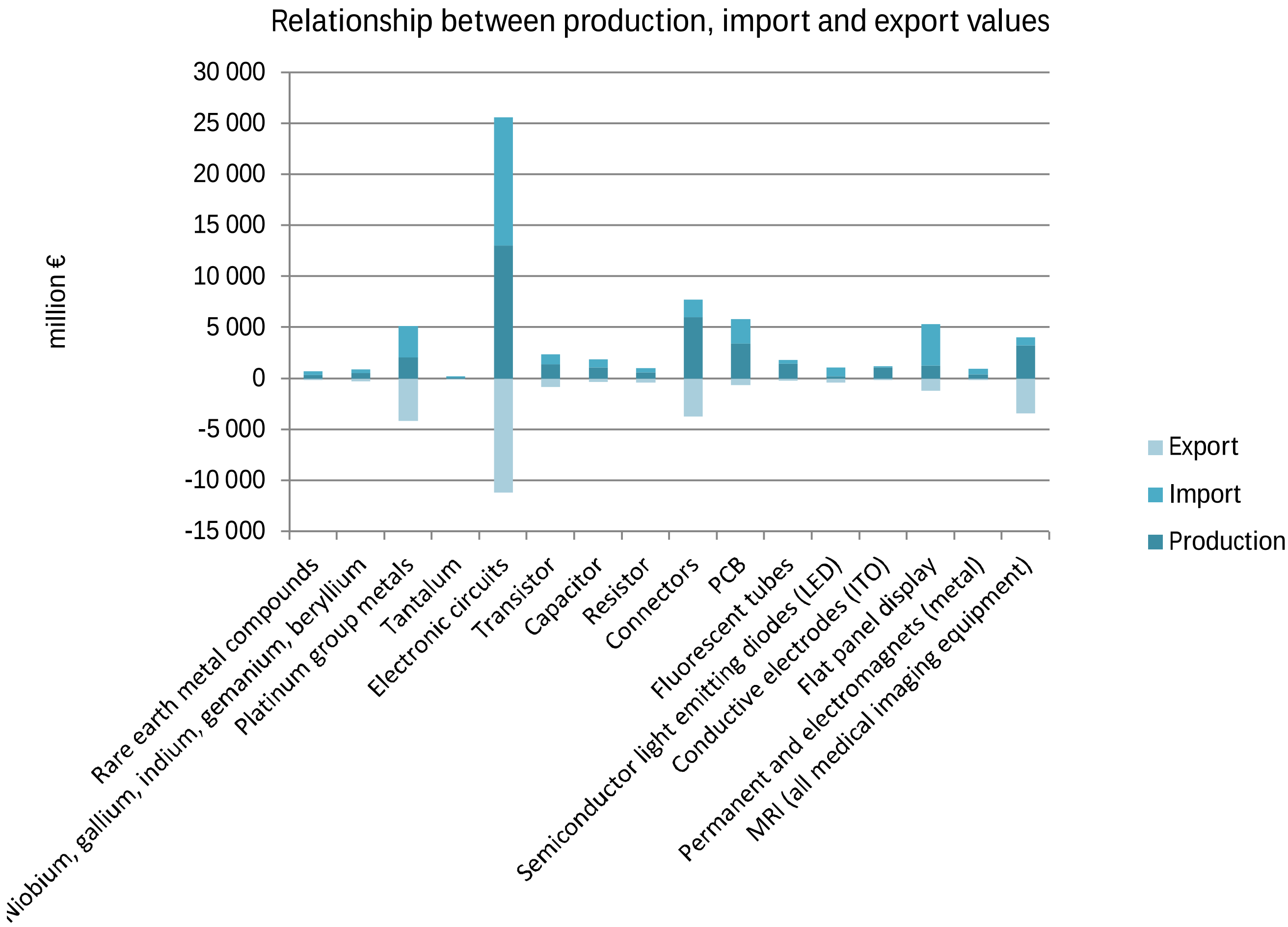


Figure 7: Relationship between production, import and export values for MRI application (including all medical imaging equipment), components and materials in Europe 2012. **Note** the values for components and materials present the whole industry, not the share which is only used in MRI.

In Figure 7 production plus import, which are presented on the positive side of x-axis, represent the cumulative value of articles which are within Europe. Consequently, the value of export is on the negative side and expresses the value of articles which leaves Europe.

Figure 7 shows that for MRI and all other type of medical imaging equipment the trade balance indicates that a number of produced applications are exported from Europe. In addition, small import value indicates a strong production of high tech applications for both domestic (in EU) and global markets. As for components, flat panel displays, LEDs, are mainly imported into Europe. Similar type of trade balance can be detected for permanent and electromagnets even though some medical companies manufacture their own magnets. A reason for this could be that only a minor share of all magnet production comes from magnets manufactured for MRI. For electronic circuits only around 40% of the whole trade comes from export indicating that a significant quantity of produced and imported electronic circuits are used as components in applications within Europe. A similar structure of the trade balance can be detected for PCB, connectors and conductive electrodes. Raw materials are mainly either produced or imported into Europe. As for exports, platinum group metals make an exception with a large export. However, larger export value than production value in platinum group metals, indicates re-export of imported articles. Generally, a country is involved in re-exports if it has a major hub in a transport network that is used to redistribute goods to neighbouring countries. Re-exports can also stem from trading positions, for instance resulting from strategic stockpiling.

Criticality

Essentiality of the role of CRM

Based on the company interviews, niobium, holmium and beryllium are essential for the functionality of high field MRI systems, without them the MRI cannot function or it becomes very expensive. No foreseeable change can replace the current setup with Nb, Ho and Be in the short term (CRM_InnoNet 2013a.), although substitutes for niobium based magnets are emerging. At the moment, also the role of the rare earths is indispensable in the production of permanent magnets for low field MRI systems. As long as low field systems are not totally substituted by higher field systems, REEs will preserve their essentiality. In conclusion, CRMs discussed in this section are essential for the MRI application they represent as they cannot be commercially substituted at the moment.

How will the vulnerability of the application evolve?

According to NioCorp Developments Ltd. (2013) around 3% of niobium produced is used in superalloys and high strength quenched and tempered plates, this category also includes the MRI manufacturing. Brazil produces around 92% of niobium, and the remaining 8% is produced in Canada. The demand for niobium has grown over the last 10 years at the compound annual growth rate of 10% and this trend is expected to continue. The global niobium demand is estimated to reach 180,000 - 200,000 tons per annum by 2018 – 2020, while the annual supply is expected to be no more than 170,000 tons. The prices of niobium have risen steadily since the year 2000, and are forecasted to remain high. Niobium producers are trying to increase the production to meet anticipated demand, and additional niobium production from new sources is probably needed. This is not enough though, and new development projects aiming to enhance niobium use will have an essential role. (NioCorp Developments Ltd. 2013.) However, the situation among the MRI industry may differ from other niobium using industries. As the MRI manufacturing industry uses only few percent of the total amount of niobium produced annually (NioCorp Developments Ltd. 2013) and if the added value of MRIs is high enough, MRI system producers are probably able to afford it and in that case no niobium shortage for this application is foreseen. The situation among beryllium and holmium is probably the same. Based on the company interviews by CRM_InnoNet (2013a), in the next three to five years there are no changes foreseen in any MRI application, nor signs of immanent future shortages caused by CRMs.

Liquid helium is used for cooling the superconducting magnets of the MRI systems. Although helium is not specified as critical raw material within the EU, it is worth noting that a major global shortage in the helium availability would have an important effect for the MRI original equipment manufacturers. The price for He has been rising at about 10% in real terms since 2000 and that is expected to continue. The price rises have forced the MRI OEMs to develop helium recondensing systems, reduce MRI helium inventory and re-liquefy helium used during manufacturing and cooldown. While long-term efforts are focused on yttrium barium copper oxide (YBCO) conductors, which may be cooled with neon or with efficient 25K cryocoolers, NbTi remains the conductor of choice - it is cheap, malleable and effective. Thus helium still prevails as the ideal coolant - but its cost and availability may negatively impact the viability of MRI compared to other cryogen-free medical diagnostic tools. (Clarke 2013.)

The imbalance between supply and demand of the rare earths will have effects on the permanent magnet manufacturing industry. Shaw & Constantinides (2012) estimated the demand for REEs used in the overall permanent magnet production to grow at 6-8% annually by 2016, whereas Gündoğdu & Kömürgöz (2012) estimated the annual growth to be around 13% by 2015. According to Constantinides (2012), magnet manufacturers have been forced to change their strategies due to the changes of the raw material prices and availability. Examples of changing strategies observed include delayed roll-out of new products, alternate magnet materials being re-evaluated and alternate permanent magnet-free technologies being developed. (Constantinides 2012.) The demand for neodymium has doubled during the last ten years, mainly driven by the increased use of the NdFeB magnets in electronic equipment (Shaw & Constantinides 2012). The demand for some rare earths important for the NdFeB magnets (such as Nd, Pr, Dy and Tb) will likely to exceed the present supply even within a couple of years (Schüler *et al.* 2011) and that may cause problems for the permanent magnet manufacturing. In the short term, the only realistic option for answering the growing demand is to open new mine sites. (Schüler *et al.* 2011.) Also the minimization of rare earth use in permanent magnets may be one option in the future (CRM_InnoNet 2013b). The heavy rare earth dysprosium is one of the biggest concerns. Dysprosium is an especially important element in the NdFeB magnet, as it raises the intrinsic coercivity (resistance to demagnetization), and thus improves magnets temperature efficiency. It is needed for magnet applications operating with elevated temperatures (which depend upon dysprosium content), that is, between 80-220 °C. (Constantinides 2012.) The use of dysprosium also improves the corrosion resistance of the permanent magnets (Avalon Rare Metals Inc. 2010). As there is no commercially available substitute for dysprosium in permanent magnets yet (Schüler *et al.* 2011), the supply of dysprosium is low and the situation is not expected to change, dysprosium is seen as the limiting factor for the NdFeB magnet production (Shaw & Constantinides 2012). Again, the situation among MRI permanent magnet industry for low field systems may be similar to high field MRI industry where no future shortages in supply are seen.

Companies in the MRI industry are trying to evade pricing pressures by investing in technological innovations. The markets for the MRI systems in Europe are in a replacement phase, in which high field systems are gradually replacing low field systems. (Frost & Sullivan 2012.) However, since permanent magnets are part of low field MRI systems that over time may be replaced by the higher field systems, the expected criticality trend for MRI is a reduction of reliance on REEs corresponding to an increased reliance on niobium.

Available substitutes

Many novel research concepts and prototypes are offering alternatives for the conventional technologies used in MRI industry. The main areas of this research include: non-traditional magnet topologies, advanced cryogenic solutions and new superconductors. Magnesium-diboride (MgB_2) has potential characteristics, such as the low cost of its chemical components, for replacing niobium-based superconducting magnets. Intensive research and material development projects and increasing interest in MgB_2-based MRI magnets have been shown in the past decade. These projects fall into two categories; low field MRI magnets that operate helium-free at temperatures around 20K, and higher field systems operated at 4.2K. The current target is that MgB_2 would be able to replace niobium magnets for mid and high field MRI magnets. Although the first commercial MgB_2 -based MRI system is now available, there are many challenges –both technical and cost issues- left before MgB_2 systems can offer commercially viable substitute for wider area of MRI systems. Another substitution option for Nb-based superconductive magnets is offered by high temperature superconductors (HTS), such as bismuth strontium calcium copper oxide BSCCO and especially the second generation conductor YBCO. Also HTS MRI developers have to resolve some serious challenges before commercial use is possible. However, Siemens/OTM has already introduced the first 0.2 tesla whole-body HTS MRI magnet that is based on a BSCCO-2223C-shaped prototype magnet. YBCO is at the moment the most studied high-temperature superconductor, and expected to be a promising technology for a broad range of commercialization. (Lvovsky *et al.* 2013.)

Environmental

Impact on European policies in case of supply disruption

Based on the life cycle analysis by Siemens Medical Solutions, their Magnetom Avanto MRI systems average annual energy consumption is about 150 mWh of electric power, which leads to about 90 tons of CO_2 emissions annually (Sterback 2007). Superconducting magnet based high and ultra-high field MRI systems consume rather high amounts of energy compared to permanent magnet based low field MRI systems, and other devices used in diagnostic radiology. According to Nakata *(undated)*, the operating power of high and ultra-high field systems varies between 22 and 44 kW/h, when permanent magnet based low field systems only use around 3 to 4 kW/h. In addition, high and ultra-high field systems require standby power supply that is around 10-16 kW/h. In comparison, the electrical power consumption of computed tomography (CT) is 5-30 kW/hr and of ultrasonography 1-1.14 kW/hr. They also calculated the CO_2 emissions per patient with different CT, ultrasound and MRI techniques used, and the results varied between 0.133 $kgCO_2$/patient (ultrasound) and 14.6 $kgCO_2$/patient (3 tesla MRI with 8 hours operating time). (Nakata *(undated)*.) Thus, if some disruption in MRI technology happened, it would lead to energy savings and CO_2 reductions, as it would probably increase the usage of other available, more energy efficient medical imaging techniques.

Innovation

Substitution activities already ongoing

No new substitution technologies aiming to replace the whole-body MRI application were found, but there are some on-going projects focusing on the development of specific magnetic resonance imaging application areas. The whole-body imaging is the dominating technology used in magnetic resonance imaging, due to its universality that enables the wide range of diagnostic needs. The high price of these devices among other things, has led to the research and development activities focusing on smaller specialty scanners and extremity imagers. These devices are dedicated to particular anatomy, such as head or orthopaedic imaging and neonatal scanning, and they provide an interesting alternative to whole body systems. These specialty magnets have a smaller imaging volume, reduced weight and coil dimensions, and thus they can offer cost and risk savings. Other specialized configurations for potential future applications include animal research MR scanners, MRI pre-polarization systems and MR hybrids (combination of an MR scanner with another imaging device or with a treatment device). (Lvovsky *et al.* 2013.) However these all are alternatives for whole-body magnetic resonance imaging, not actual substituting technologies for MRI application.

4.1.3 MRI – business summary

A summary of business analysis is presented in Table 6.

Table 6: A qualitative summary table of MRI.

Dimension	Criterion	Required input
economic	Economic value of application or area	• **The market revenue of MRI manufacturing in Europe was \$886.4 million (€668.5 million) in 2011.** • **The production of all type of medical imaging apparatus in Europe was approximately €3.2 billion in 2012 (Eurostat 2012).**
	Position of EU in entire supply chain	**Magnets:** • **The main MRI system manufacturers (GE Healthcare, Siemens Medical Solutions and Philips Healthcare) have their own superconducting MRI magnet production, also in Europe.** • **Permanent magnet production is dominated by China. European companies are mostly focused on manufacturing semi-finished or finished products.** **MRI Systems:** • **The market share of Siemens Medical Solutions, GE Healthcare, and Philips Healthcare, exceeds 70% in MRI manufacturing.**
	Jobs involved in the EU	• **46,000 persons employed in 2010 in manufacture of irradiation, electro medical and electrotherapeutic equipment sector.** • **430,000 persons employed in 2010 in manufacture of medical and dental instruments and supplies sector.**
criticality	Essentiality of the role of CRM	• **Nb is needed for the production of superconducting magnets. Also He is essential for the high field systems.** • **Rare earths are essential for permanent magnet production, Nd as the most important one. Also small amounts of Dy, Pr and Tb. Low field MRI systems have a minor role in the overall MRI market, but as long as these systems are not totally substituted by superconductive systems, REEs will preserve their essentiality.**
	How will the vulnerability of the application evolve (as a result of RM and market developments)?	• **Shortages in supply for CRMs needed in the high field MRI application are not probable in the short term.** • **The markets for MRI systems in Europe are in a replacement phase in which high field systems are replacing permanent magnet based low field systems. A compound annual growth rate (CAGR) 4.9% is predicted between 2011 and 2018.** • **Eastern European MRI markets have more growth potential than Western European in the future.**
	Available substitutes?	**R&D activities for substituting Nb-based superconducting magnets with:** • **Magnesium-diboride (MgB_2)** • **High temperature superconductors (HTS), such as BSCCO and especially the second generation conductor YBCO. (Lvovsky *et al.* 2013.)**
environ mental	Impact on European policies in case of supply disruption	**Possible energy savings and CO_2 reductions, if disruption situation would lead to the increased use of other medical imaging techniques as they consume less energy.**
innovation	Substitution activities already ongoing? What is the status of that research?	**No evidences of on-going substitution activities for whole body MRI systems. Specialty MR scanners and extremity imagers can offer cost and risk reductions compared to whole body systems (Lvovsky *et al.* 2013).**
	Principle of substitution: is substitution conceivable?	**-**
	Opportunity for Europe	**Europe has a strong position in medical technology industry. R&D potential for new products and methods which consume less CRM and are more energy efficient may create opportunities for Europe.**

4.2 LED lighting

4.2.1 LED lighting technologies and CRM dependence

In the past few years the usage of light-emitting diodes (LEDs) in lighting has become more popular. LEDs have many benefits compared to the traditional lighting sources, for example; they are highly efficient, sustainable and safe products, with good switching stability and start-up characteristics. The price level of LEDs is continuously decreasing and their usage gives savings in the long-term, because LED products have a long service life. The convenient small size also brings new opportunities in their use, for example in the automotive industry and room lighting. (Buchert *et al.* 2012, Frost & Sullivan 2013a.) The key sectors for LEDs are general lighting, automotive lighting, and backlighting on displays and mobile phones. This section mainly focuses on LEDs used in general lighting.

A light-emitting diode is basically a semiconductor device that produces light when electric current is allowed to flow in only one direction. A LED die consists of adjacent layers of n- and p-doped semiconductors (III-V) and a depletion layer between them. The n-conductive layer has an excess of electrons while in the p-conductive layer the situation is opposite. The difference between the quantities of electrons causes them to move from the n-layer to the p-layer when a voltage is applied. This transition releases energy in a form of light. The wavelength (and thus the colour) of the light emitted is dependent on the band gap energy of the materials forming the p-n layers. A combination of a III semiconductor and a V semiconductor is needed to build this band gap. (Deubzer *et al.* 2012, Buchert *et al.* 2012.)

The composition of LED lighting is presented in Table 7.

Table 7: Structural composition of LED lighting.

Light emitting diode (LED)	CRM content	Comments
LED module		
LED		
Semiconductor die	In, Ga	
Phosphors	Ce, Y, Tb, Lu, Eu, Gd	
Electronics		
Printed circuit board		
Plating	Pd	Not very common to use Pd as plating, generally Ni/Cu and Au are used
Components		
Capacitors	Ta, Pd, Nb	
Resistors	Ta, Ru	
Semiconductors	Ga, Ge, In, Sb	
Transistors	Ga, Ge	
Connectors	Pd, Ru, Be	
Cables		

Two critical raw materials, gallium (Ga) and indium (In) are used as semiconductor components. Critical materials are also essential in phosphor substances used when aiming to accomplish the impression of natural light, because LEDs only emit light on a discrete wavelength with a specific band gap (Deubzer *et al.* 2012, Buchert *et al.* 2012). There are two main groups of phosphors that are used in significant quantities: A) garnet phosphors; cerium (Ce) -doped YAG (yttrium aluminium garnet) and TAG (terbium aluminium garnet), or LuAG (lutetium aluminium garnet) based on yttrium (Y), terbium (Tb) and lutetium (Lu), and B) europium (Eu) –doped ortho-silicates (Deubzer *et al.* 2012).

Deubzer *et al.* (2012) analysed, based on six studies, the criticality and the economic relevance of the raw materials contained in the LED dies, packages and modules. As a result of their study rare earth metals (yttrium, cerium, terbium, lutetium and europium) were defined as highly critical and economically important for the electronic industry, indium as highly critical but not very economically important, and gallium as critical but not very economically important, although its economic importance was expected to grow due to the strong rise of the demand.

The quantities of elements and the exact compositions of different materials used are mainly based on estimations, because manufacturers do not usually report them. On this account, the following data is based on empirical values and must be taken as a general indication. The size and the weight of a semiconductor die vary between manufacturers, and it is a notable variable when estimating material quantities. It also makes forecasting of the amounts used in LEDs difficult. (Buchert *et al.* 2012.) Buchert *et al.* (2012) assessed the typical content (weight per LED) of critical metals in a $In_xGa_{1-x}N$ semiconductor die, typically used in a white LEDs, to be: In 29.0 µg, Ga 32.5 µg, Ce 2.0 µg, Eu 0.6 µg, Gd 15.0 µg, and Y 32.0 µg, while Angerer *et al.* (2009) assumed a LED die to be significantly larger, and In content to be 170 µg and Ga 530 µg. White LEDS are used for example in backlighting and general lighting. Figure 8 represents the estimated percent by weight shares of the individual elements used in white LEDs according to Buchert *et al.* (2012).

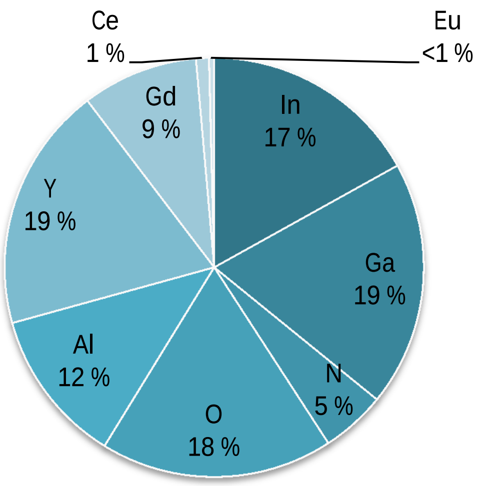


Figure 8: Percent by weight of elements used in a wLED. Indium, gallium and nitrogen occur in semiconductor die, others in phosphorous material (Buchert *et al.* 2012, modified).

Angerer *et al*. (2009) set up two different scenarios (A and B) for estimating the amount of LEDs manufactured in the period 2006 – 2030. They assumed that the number for white and high-brightness LEDs in 2009 was between 21 and 37 billion products manufactured. In the year 2030, the more conservative scenario A assumes the quantity of LEDs manufactured to be around 141 billion, and the number of wLEDs approximately 84 billion (60%). Scenario B prefigures the markets to be more dynamic and concludes the amount of LEDs manufactured to be around 388 billion. In this scenario the proportion of wLEDs in 2030 is around 70%, 271 billion products. The third scenario (C) is originally presented by Young (2011), cited by Buchert *et al.* (2012). It estimates the growth rate of white LED production to increase between 2009 and 2020, but after that the growth becomes quickly saturated. Table 8 provides more detailed information about the studies above-mentioned.

Table 8: The estimation of the number of white LEDs and all high-brightness LEDs produced between 2006 and 2030 (billions) (Angerer *et al.* 2009, Buchert *et al.* 2012, modified).

Scenario	LED type	Number of LEDs [billions]					
		2006	2009	2011	2020	2025	2030
A	wLED	15	21	25	45	62	84
	LED	31	37	42	75	103	141
B	wLED	15	21	25	97	162	271
	LED	31	37	42	149	241	388
C	wLED (number of GaN dies)	-	24	71	164	164	165

Based on the scenarios A and C, Buchert *et al.* (2012) also presented estimations of the global future demand for some of the critical raw materials used in manufacturing white LEDs (Table 9).

Table 9: The refined raw material production outputs and estimates of the future demand for gallium, indium, cerium, europium and yttrium, for the manufacture of white LEDs (Salazar & McNutt 2011, 2013, Buchert *et al.* 2012).

Raw material	World production in 2010 (and 2012) [tons]	Use in wLEDs [tons]				
		2010	2015	2020	2025	2030
Gallium	161 (354)	0.75-1.56	1.07-4.90	1.46-5.34	2.00-5.35	2.74-5.35
Indium	574 (670)	0.67-1.38	0.95-4.37	1.30-4.76	1.78-4.78	2.45-4.78
		Use in wLEDs [kg]				
Cerium	40,000	46-96	66-301	90-329	123-329	169-329
Europium	400	14-29	20-?	27-99	37-99	50-99
Gadolinium	4,000	347-720	492-2,260	674-2,470	923-2,470	1,260
Yttrium	8,900	739-1,540	1,050-4,820	1,440-5,260	1,970-5,270	2,700-5,270

On the basis of the typical metal content of LEDs and the production forecasts, Angerer *et al*. (2009) evaluated the demand for gallium and indium for manufacturing wLEDs. The global demand for gallium was estimated to grow from 9 tons in 2006 to 44 - 143 tons in 2030, and for indium from 3 tons to 14 - 46 tons respectively. The estimated size of LED die used in the forecasts causes the remarkable difference in the Ga and In demands between the Buchert and Angerer studies. However, according to Salazar & McNutt (2013), 29% of gallium went into optoelectronic devices in 2012 and based on that estimate, Angerer's figures seem more realistic.

Marwede *et al*. (2012b) calculated the amount of gallium in the LED general lighting products put on the European market to be around 5 kg in 2011, and little more than 50 kg by 2020. Comparing the amount of gallium used in the production process and the amount in the end applications, it seems that probably due to the dissipative manufacturing process of LEDs, the most of gallium is lost during the manufacturing. Thus only low gallium concentrations are presented in the actual lighting products. Currently, the European research project cycLED (www.cyc-LED.eu) is aiming to assess the amounts of the other critical materials contained in LED lighting products.

Critical raw materials are also used in the printed circuit boards of LED drivers. Deubzer *et al.* (2012) estimated that the material composition of PCBs on LEDs is similar to the electronics needed for a cold cathode fluorescent lamp. Based on this, the electronic components and solders of the LED driver contain around 0.0012% palladium (Pd) and 2.7% antimony (Sb). (Huisman *et al.* 2007, Deubzer *et al.* 2012.) The electronic components in PCBs may also contain other CRMs than presented here (see Table 7), however no specific information about the amounts of these components is available. A detailed analysis of assembled printed circuit boards is presented in section 4.6.

In addition to the LEDs themselves, the LED products also contain different kinds of critical materials in their electronic components. LEDs are used in LCD displays, mobile phones and lighting products to mention but a few.

4.2.2 Analysis of CRM-related LED lighting market and supply chain

Economics

LED die market

Most basic LED dies are made in Asia (78%), Japan as the leading country with 37% of production share (Pearsall *et al.* 2012, cited by Deubzer *et al.* 2012). MOCVD (metalorganic chemical vapour deposition) is an essential method in single or polycrystalline thin film manufacturing, which is used as a base for LED die production. MOCVD is the most popular method to manufacture HB-LEDs (Frost & Sullivan 2013b). Asia was estimated to account for 90% of global demand for MOCVD systems to produce thin films in the year 2012, which was about 10% more than in 2011. LED manufacturers in Japan had the highest total estimated output value (including modules) in 2012, about $3.6 billion (€2.72 billion), followed by South Korea with $3.2 billion (€2.41 billion), and Taiwan with $1.69 billion (€1.27 billion), because of Taiwan focusing on the production of LED components. However, excluding modules from the output data, Taiwanese manufacturers bypass South Koreans. Chinese manufacturers mainly produce medium and low power LEDs. The output value in China was around $1.42 billion (€1.02 billion) and they were expected to account for 68% of MOCVD demand in 2012. (Lin 2012.)

LED lighting market

LED markets are evolving fast. In 2011, the size of the LED lighting markets was estimated to be approximately 12% (€9 billion) of the entire global lighting markets. However, this market share is expected to grow rapidly over the next few years, rising to a market share of more than 40% in 2016, and over 60% by 2020, with revenues of approximately €64 billion. The key sectors for LEDs are general lighting, automotive lighting, and backlighting on displays and mobile phones. Backlighting is the most important market driver at the moment with a LED value-based market share of 57% in 2011, but it is expected that the share of LEDs in the market will soon gain 100%. In addition, it is assumed that the markets will soon move from LCD TVs to OLED TVs, in which backlighting is not used at all. Also the development towards brighter LEDs leads to a decreasing number of LEDs required in devices. The 2011 market share of LEDs in automotive lighting, 13%, mainly originated from red LED applications used as indicators and brake lights. The automotive market will continue its growth (expected 36% share by 2020) because LED lights are increasingly used as automotive headlamps. General lighting represents the mainstream of the lighting. The market for LEDs in general lighting was only 9% in 2011, but due to cost reductions and energy-saving goals, the share is expected to grow from 45% in 2016 to 69% by 2020. (Figure 9) (McKinsey & Company 2011, 2012.)

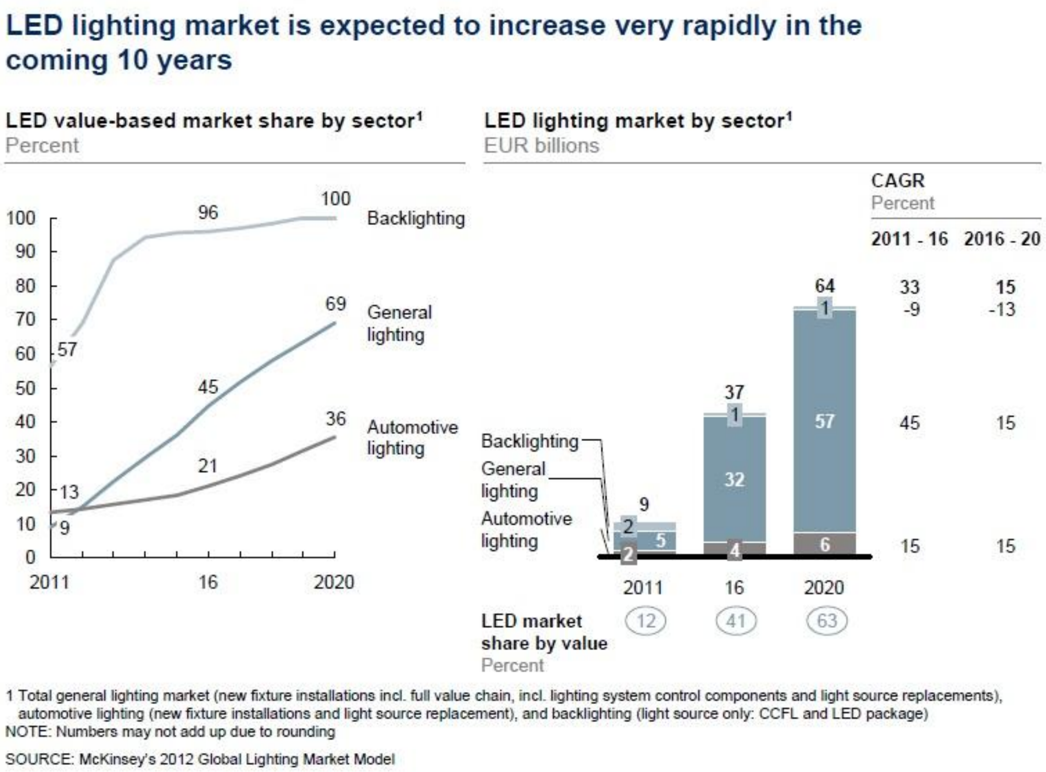


Figure 9: The increase of the global LED lighting markets between 2011 and 2020 (Exhibit from "Lighting the way: Perspectives on the global lighting market, 2nd edition." 2012, McKinsey & Company, www.mckinsey.com/insights. Reprinted by permission.)

General lighting market

General lighting is the leading sector in the total lighting markets. It can be divided into seven different applications; residential, office, shop, hospitality, industrial, outdoor, and architectural. At the moment, architectural lighting, the prime early adopter of LED, has the highest value-based market share, 47%. The market share is expected to grow from 76% in 2016, to 88% by 2020. In the total lighting markets residential lighting is, and will be, the largest segment followed by office and outdoor segments, accounting for almost 40% of the total general lighting market in the year 2011. It is also assumed to become the most important LED lighting application in the future. The LED value-based market share in residential lighting is around 7% at present. By 2020 this share is expected to be as big as 73%. (Figure 10) (McKinsey & Company 2011, 2012.)

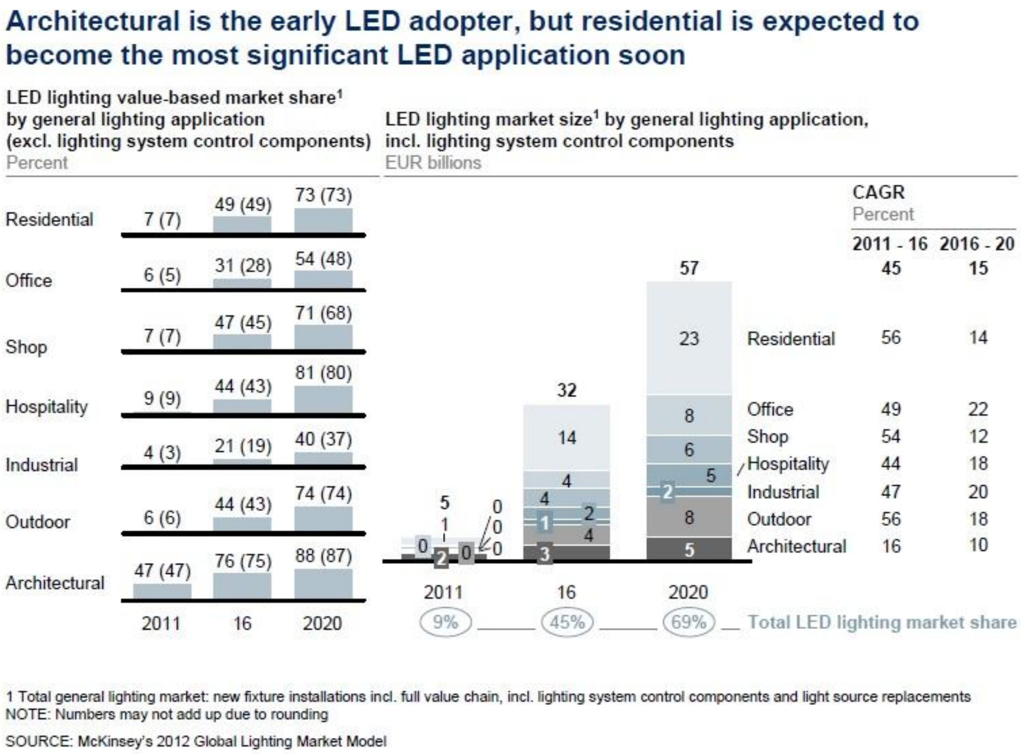


Figure 10: LED lighting value-based market shares and LED lighting market sizes (€ billions) by different general lighting applications (Exhibit from "Lighting the way: Perspectives on the global lighting market, 2nd edition." 2012, McKinsey & Company, www.mckinsey.com/insights. Reprinted by permission.)

Due to the lack of reported global and European production data on LED lighting, the focus on this economic analysis is on value-based revenues. Asia is currently the largest total general lighting market, and its position is expected to remain strong due to strong economic growth focused in some Asian countries. Asia also dominates the global LED general lighting market with 40 - 50% of the total market, growing to markets of €26 billion by 2020. In Europe, the current LED general lighting market size was around €1 billion in 2011 and the market is expected to achieve the size of around €14 billion by 2020. LED lighting currently represents a value-based market share of 9% of total lighting in Europe. This share is expected to rise to approximately 47% by 2016 and 73% by 2020. (Figure 11) (McKinsey & Company 2011, 2012.) Germany and the United Kingdom are currently the two forerunners in LED lighting in Europe. The countries in Western Europe are important for growth in the short and medium term, while in the long term, the growth is largely focused on Central and Eastern Europe. (Frost & Sullivan 2012b.) The sales volumes of different LED general lighting applications in Europe are predicted to increase strongly in the coming years, resulting to almost 700 million units by 2020. (Marwede 2012a, based on a data published by McKinsey & Company 2011.)

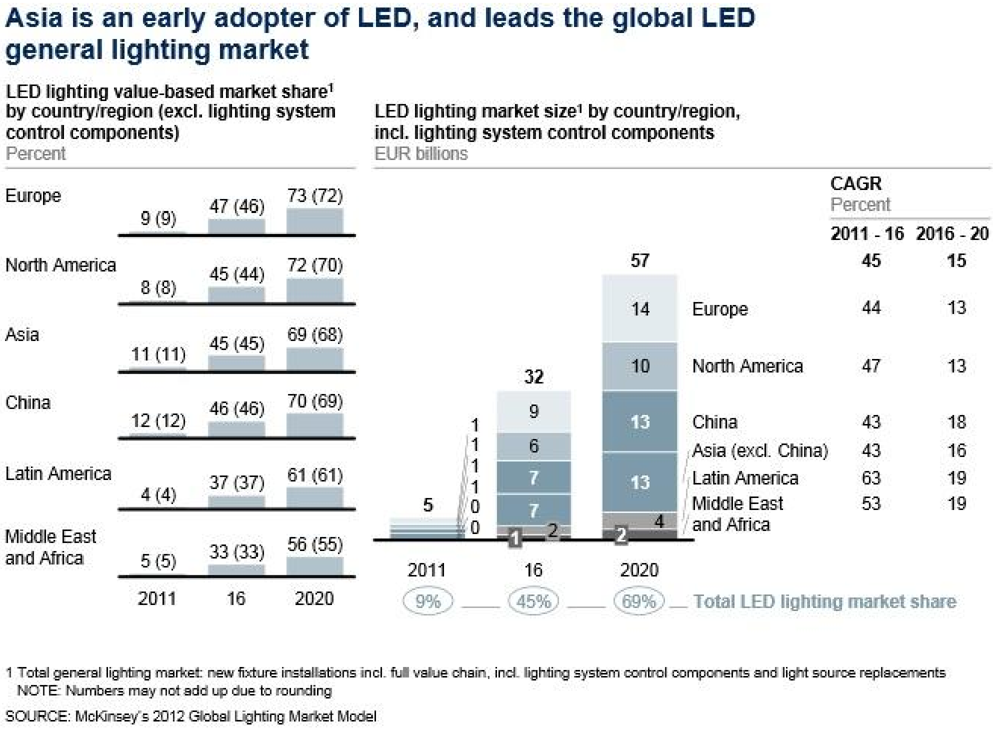


Figure 11: Asia is the leading continent in LED general lighting value-based market shares (%) and LED general lighting market sizes (€ billions), followed by Europe and North-America (Exhibit from "Lighting the way: Perspectives on the global lighting market, 2nd edition." 2012, McKinsey & Company, www.mckinsey.com/insights. Reprinted by permission.)

Based on the data from Eurostat's centralized PRODCOM data base the production in the EU as a value for *Lighting sets for Christmas trees; Searchlights and spotlights (including for stage sets, photographic or film studios); Electrical lighting or visual signalling equipment for motor vehicles (excluding electric filament or discharge lamps, sealed beam lamp units, ultraviolet, infrared and arc lamps); Electrical signalling, safety or traffic control equipment for railways or tramways; Electrical signalling, safety or traffic control equipment for roads, inland waterways, parking facilities, port installations or airfields* groups which contains LED applications was approximately €7.3 billion in 2012. In addition, import into the EU and export from the EU for the same product group was approximately €1.1 and €2.0 billion respectively. (Eurostat 2012.)

Position of EU in supply chain and main actors

The supply chain of LED lighting consists of six steps. In addition, the supply chain can include parallel streams for different components including CRM. The supply chain of LED lighting is presented in Figure 12. The supply chain is focused on light-emitting diodes, other components including CRM are presented later in Figure 14.

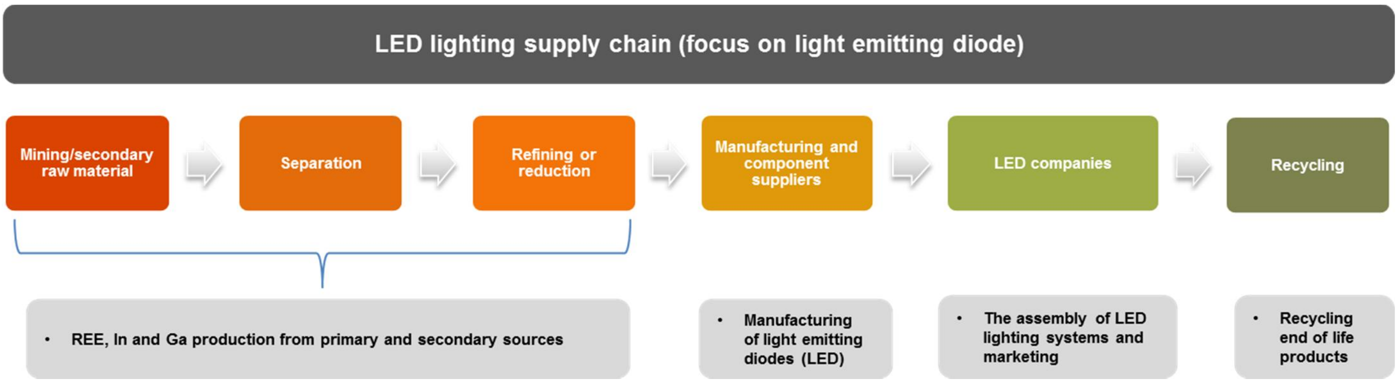


Figure 12: LED lighting supply chain focused on light-emitting diode.

The supply chain can be roughly divided to four different stages. The first stage is raw material production from primary or secondary sources. The material can be in the form of pure metal powder or alloy. The second stage is the manufacturing of light-emitting diodes or a module LEDs. The third stage of the supply chain is the assembly of the components to produce a comprehensive lighting solution which can be marketed and sold. In some circumstances the light-emitting diode manufacturer might also produce whole lighting systems (Gereffi 2008). In other words the component producer can have also end product production. The final stage of the supply chain is the recycling end of life products.

Taiwan, Japan, South Korea and China are the major countries with a significant LED die manufacturing industry (SEMI 2010). Pearsall (2012) estimated the regional production shares of HB-LEDs as follows: Japan 37%, Korea 20%, Taiwan + China 20%, US 15% and Europe 7% (Deubzer *et al.* 2012). In 2011, 3% of each GaN and InGaAlP LED production capacity located in Europe (EPIC 2010, cited by Deubzer *et al.* 2012).

The number of European manufacturers of LED dies (European Commission 2011a) and components is limited (Butter *et al.* 2011). Osram Opto Semiconductor is the main producer of actual LEDs, since another significant LED maker Philips Lumileds produces its dies mostly in North-America and Asia (Hatcher 2011). Osram OS's share of the global LED supply was about 7% in 2011 (Pearsall *et al.* 2012, cited by Deubzer *et al.* 2012). Also Russian-originated Optogan has a LED die production facility in Germany, and describe it as the second largest LED die production site in Europe (Whitaker 2011). According to SEMI (2010) only four manufacturing companies were located in the Europe and Middle East region in 2011. Conversely, the market of manufacturing the components into actual light sources is highly represented in Europe (Butter *et al.* 2011).

The number of companies in the total general LED lighting market is around 4,000 – 6,000 globally. However, the market is highly concentrated in the hands of the few leading companies. The major three participants (GE Lighting, Osram AG and Philips Lighting) had a market share of 52%, and amongst the ten largest competitors this share was 77% in 2011. (Frost & Sullivan 2012b.)

At European level, there are approximately 750 – 1,000 companies competing in the general LED lighting market, Philips Lighting as the leading company. Along with Osram AG and Havells-Sylvania they account for 62% of sales in Europe. Their position in the European market is also predicted to remain strong at least in the short and medium run. GE Lighting, Megaman, Tridonic Atco, and Cree Inc. are other important companies in Europe, and a common market share of these seven competitors is around 82%. In the future, some East Asian companies are expected to have a growing presence in Europe. (Frost & Sullivan 2012b.)

A summary of the main actors in the LED lighting supply chain is presented in Figure 13.

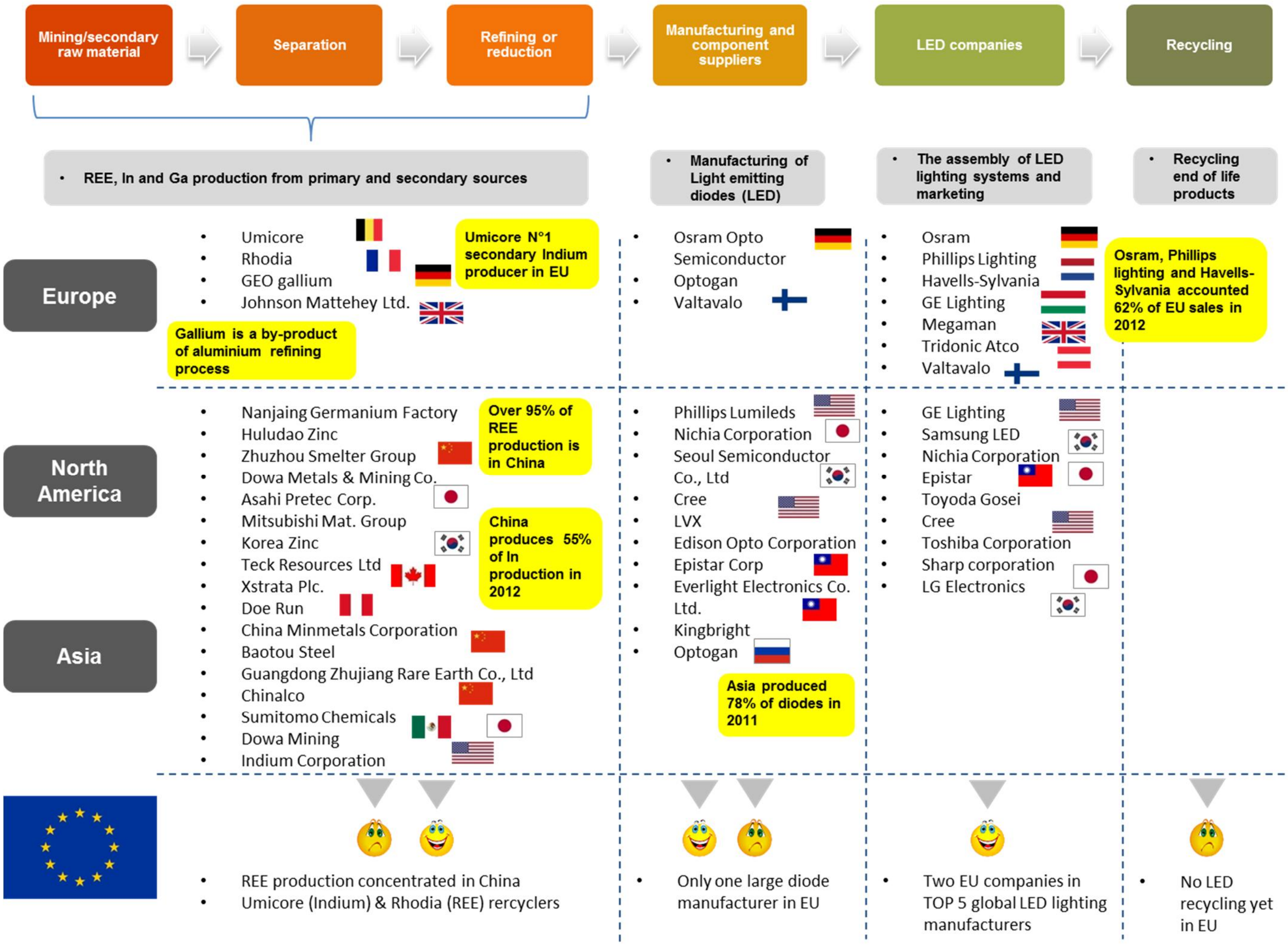


Figure 13: A summary of main actors in LED lighting supply chain.

Jobs involved in EU

Based on Eurostat's structural business statistics, the manufacturing of electronic components sector which include LED production employed 220,000 people in 2010 within the EU. The largest employing country was Germany providing employment for over 55,000 people. In addition, the manufacturing of electric lighting equipment sector employed nearly 155,000 people in 2010 within the EU. Germany employed approximately 38,000 people while the next largest employing countries were Italy, France, Poland and the United Kingdom providing employment for between 15,000 - 18,000 people respectively. (Eurostat 2010b.) European Lamp Companies Federation together with CELMA (2011) has divided the Eurostat's (the manufacturing of electric lighting equipment sector) 155,000 employees to three different production levels in order to correspond different supply chain stages:

1. LED die and package level < 1%
2. LED package on PCB and lamp/module level 25%
3. LED luminaire or similar device level 75%

However, direct employment of LED production is less than reported above, since the Eurostat sector includes also other type of lighting.

EUROSTAT data interpretation

The quantitative supply chain analysis was carried out on data from Europe's PRODCOM database. More detailed information on the data and application composition can be found in Appendix 3 (LED data). The data from PRODCOM has been applied to produce supply chain illustration for production with largest producing countries in Europe (Figure 14). **However, it is essential to understand that the shares/dimensions of different industries (box sizes) represent the production for the whole industry not only the share which is used in LED lighting production.**

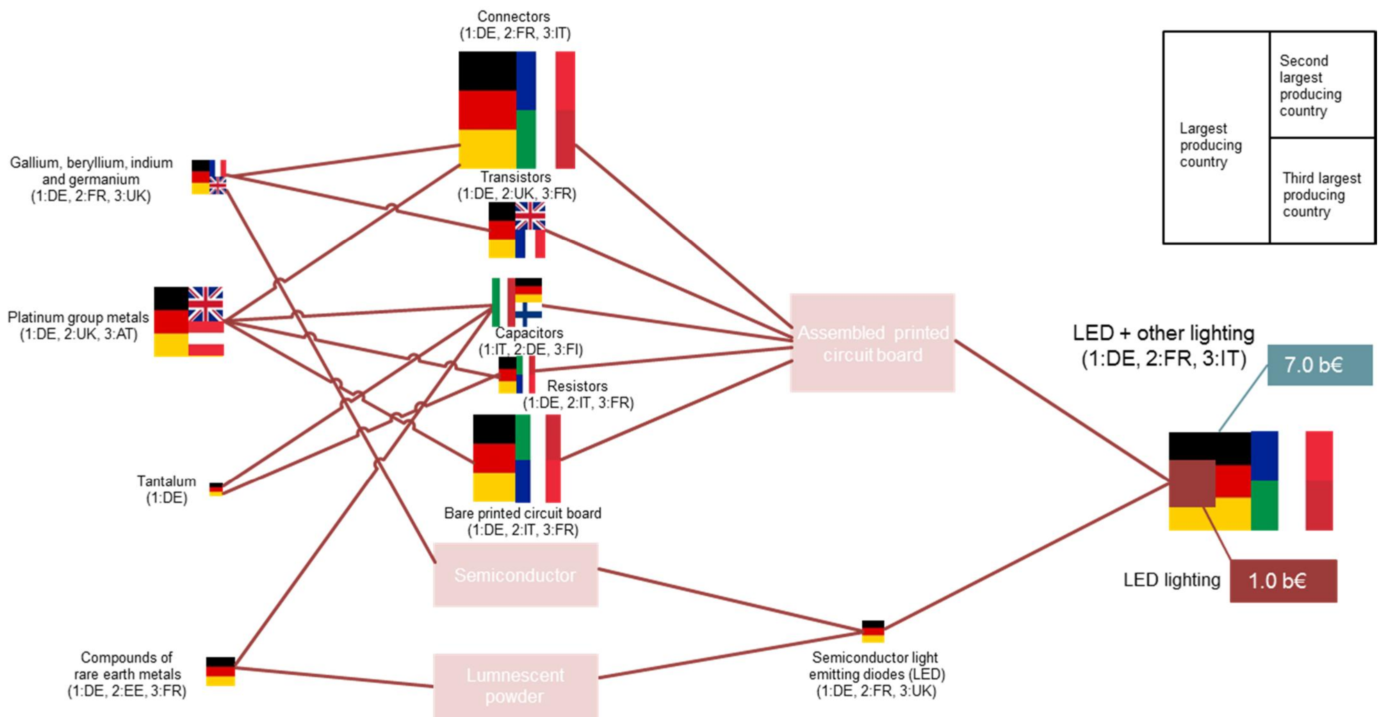


Figure 14: EU production of LED lighting and related (sub)-components and materials. (Sub)-components in pink boxes have no corresponding PRODCOM group and therefore no statistically defined value and are included for completeness. The green box represents the total value for all lighting and therefore red box inset presents the value of LED lighting production based on data from a market report by McKinsey & Company (2011). Each box presents the total production value, not the value of components/materials which are used only in LED lighting applications. In addition, the largest EU producing countries are presented.

The production in the supply chain of LED lighting exists both on component and end application level. However, a trend of production focused at the end part or the supply chain can be detected. In addition, a strong European electric component production industry can be noticed. In the material supply stage of the supply chain, all other materials except platinum group metals have less production than the component or application production.

The largest producing country is Germany almost in every step of the supply chain. In the end application production Osram has several factories in Germany. As for LED die production both Osram Opto Semiconductor and Optogan have a LED die production facility in Germany. Other significant producer countries are France, Italy and the UK. While Italy and France are focused more on component and end application production, the UK is more on component and material production. The UK has platinum group metals production with companies such as Johnson Matthey Ltd.

The balance between production, import and export in the supply chain of LED lighting is presented in Figure 15.

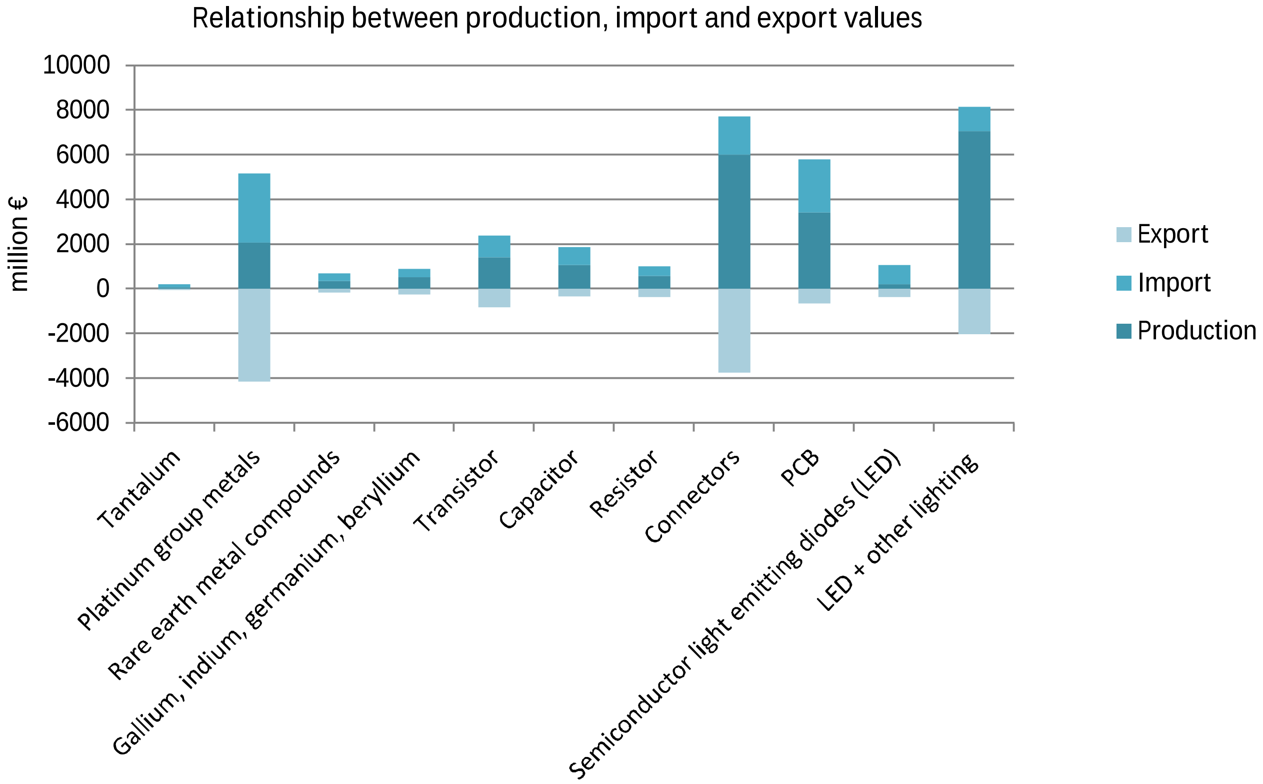


Figure 15: Relationship between production, import and export values for LED and other lighting application, components and materials in Europe 2012. **Note** the values for components and materials present the whole industry, not the share which is only used in LED lighting.

In Figure 15 production plus import, which are presented on the positive side of x-axis, represent the cumulative value of articles which are within Europe. Consequently, the value of export is on the negative side and expresses the value of articles which leaves Europe.

Figure 15 shows that production dominates the trade balance for LED and other lighting. In addition, low export value and high import value indicates high consumption of European products within Europe. As for LED diodes the trade balance is dominated by import which supports the business analysis where LED die production is located mainly outside Europe. The large production and import values as well as low export value of PCB indicates further use as a component in end applications within Europe. Similar balance could be noticed for connectors. Raw materials are mainly either produced or imported to Europe. As for exports, platinum group metals make an exception with a large export. However larger export value than production value in platinum group metals, indicates re-export of imported articles. Generally, a country is involved in re-exports if it has a major hub in a transport network that is used to redistribute goods to neighbouring countries. Re-exports can also stem from trading positions, for instance resulting from strategic stockpiling. As for gallium, indium and germanium metals larger production than import value supports the business analysis where production of these metals from secondary sources in Europe had been identified.

Criticality

Essentiality of the role of CRM

The role of critical raw materials is essential in the LED production process. European Lamp Companies Federation together with CELMA (2011) categorized gallium, indium, europium and yttrium used in LEDs and phosphors as materials that are "highly suited for the application and cannot be replaced," or their replacement is almost impossible. However, LED die production is mainly focused outside Europe and thus the European link to the CRM essentiality is indirect.

How will the vulnerability of the application evolve?

Based on the previous estimates, the future overall markets for LED products do not seem very vulnerable at least in the short and medium term. In the long term, the development of new technologies and products, and the possible saturation of some market sectors might have effects on markets. Because the market position of LEDs does not seem vulnerable, the vulnerability of LED application depends on the accessibility of the critical raw materials essential for manufacturing. Any reductions in access to LED dies would impact European LED product manufacturing, because of the small number volume production of actual LED die producers located in Europe, however there is no indication related to this risk at the moment.

Available substitutes

Although technological improvements will presumably lead towards resource-efficiency in the future, the global consumption of critical raw materials will increase because of the prolific aggregate demand for LED products. A concern about sufficiency of these materials has led to attempts at developing substitutes for these materials. Most of these substitutes are still at the research stage, but some are already in use. Even if substitutes are already available or being developed for gallium in many applications, it is unlikely, that the complete replacement of GaAs in all semiconductor applications will take place in the future. It is possible to replace certain materials is some cases, but the difficulty is that this replacement typically relies on another rare material. (EPOW 2011.) Substituting gallium has so far been difficult though, since substitutes easily suffer from reduced performance (Halme *et al.* 2012). Other examples of substitution strategies in a research and development stage or already available are; 1) Substituting gallium nitride (GaN) used as a functional material in blue LEDs, by zinc oxide (ZnO) or magnesium sulphide (MgS). This substituting substance for substance project is still at the R&D stage, but may lead to annual savings in gallium material costs of €100 million, and also aims to create over €2 billion/year direct business with these new products. 2) Substituting rare earth materials yttrium, europium and terbium used as phosphorous materials in LEDs, by quantum dots which replicate the wavelength shift properties. As a result, longer lifetimes at lower power consumption will be achieved. However, it has to be integrated into other technologies (e.g. OLEDs). (SusChem 2011.) 3) Substituting indium-based semiconductors by zinc oxide (ZnO). However, the required p-type ZnO has limited stability and it is not (yet) a feasible substitute for indium. 4) Also development of REE free phosphors for LEDs is under way. (CRM_InnoNet 2013b.)

Other available substitution options for raw materials used in LEDs are discussed in CRM_InnoNet (2013b) report “Raw Material Profiles”.

Environmental

Impact on European policies in case of supply disruption

McKinsey & Company (2012) compared several different kinds of clean technologies in terms of their commercial viability, and LED technology was selected to be the most promising technology in 2020 (McKinsey & Company 2012). The LED market share is constantly growing, and it is presumable that LED applications are going to substitute most incandescent light bulbs within the next decade. Legislation, increasing awareness to act in a more socially responsible way, and intentions to sustainable practices are driving societies to greener solutions. Using LED products leads us to more efficient and more sustainable lighting solutions due to their longer durability and energy efficiency. Governments in many countries around the world are currently promoting this transition by giving regulations that ban environmentally unfriendly and energy inefficient lighting solutions in the future. (Frost & Sullivan 2013a.) Europe is one of the forerunners in providing more energy efficient solutions. The current policy of European Union is directing countries to cut greenhouse gas emissions by 80-95% by 2050 (European commission 2011b). Europe also started to phase out inefficient and environmentally wasteful lighting by banning the incandescent light bulbs in 2012 and discussions around phasing out halogens by 2016 are under way. The same trends are also observed globally, although in a longer timeframe, and this drives increasing demand for LEDs. In the coming years, Asia, led by China, is most likely to be the leading growth zone of LEDs in terms of volume. As the LED markets are constantly increasing, the demand for materials and chemicals used in LED manufacturing is also growing. New innovations are needed not only for the evolution of certain components, but also for improving or replacing substrates and additives used in LEDs. Also emerging new applications support the deployment of LED lights in new sectors and thus strengthen the market development potential. (Frost & Sullivan 2013a.) According to the recent analysis by McKinsey & Company (2012), replacing traditional lighting technology with energy-efficient technologies such as LEDs will provide substantial economic benefit, and at the same time reduce CO_2 emissions. In case of some disruption in the LED lighting markets, these goals will become much harder to achieve.

Innovation

Substitution activities already ongoing

According to Halme *et al.* (2012) and EPOW (2011) LEDs used in backlighting on displays and mobile phones can be replaced by LEDs made of organic compounds (OLEDs), and the more developed versions of these kind of processes may well reduce gallium dependence in the future. OLED technologies are still emerging, but it is forecasted that OLEDs may replace LEDs especially in the general lighting and backlighting markets and even in large-screen TVs. Although the extent of OLED penetration is still unclear in the general lighting market, the penetration is already seen in the mobile/smart phone market. It is assumed that the backlighting markets will soon move from LCD TVs to OLED TVs. (McKinsey & Company 2011, 2012.)

4.2.3 LED – business summary

A summary of business analysis is presented in Table 10.

Table 10: Qualitative summary table of LED lighting.

Dimension	Criterion	Required input
economic	Economic value of application or area	• In 2011, the size of the global LED lighting markets was around €9 billion. By 2020, revenues of approximately €64 billion are expected. • The production of all type of lighting in Europe was approximately €7 billion in 2012 (Eurostat 2012b).
	Position of EU in entire supply chain	• LED die production in Europe is limited compared to Asia. Osram Opto Semiconductor is the single leading European producer of LED dies. • The manufactures of actual light sources are well represented in Europe. In the general LED lighting market Philips Lighting, Osram AG and Havells-Sylvania account for around 62% of EU sales.
	Jobs involved in the EU	• 155,000 persons employed in 2010 at manufacturing of electric lighting equipment sector in EU. • In addition, 180,000 persons are employed in 2010 at manufacturing of other electrical equipment sector, from which a share can be producing lighting equipment to electrical signalling.
criticality	Essentiality of the role of CRM	Very essential, however, LED die production is mainly focused outside Europe and thus the European link to the CRM essentiality is indirect.
	How will the vulnerability of the application evolve (as a result of RM and market developments)?	The future overall markets for LED products do not seem very vulnerable at least in the short and medium term. Availability of LED dies may form a bottleneck for European industry. However, there are no indications on that risk currently. The vulnerability depends on the accessibility of the critical raw materials.
	Available substitutes?	Substituting gallium has been difficult so far, since substitutes easily suffer from reduced performance. Other examples: • Substituting gallium nitride (GaN) by zinc oxide (ZnO) or magnesium sulphide (MgS) (R&D stage) • Substituting rare earth materials yttrium, europium and terbium used as phosphorous materials in LEDs, by quantum dots which replicate the wavelength shift properties (commercial) • Substituting indium-based semiconductors by zinc oxide (ZnO) (not (yet) a feasible substitute) • Development of REE free phosphors for LEDs See also CRM_InnoNet (2013b) report “Raw Material Profiles” for other substitution options.
environ mental	Impact on European policies in case of supply disruption	Losses in energy efficiency and economic benefits. Harder to achieve goals for GHG emission reduction.
innovation	Substitution activities already ongoing? What is the status of that research?	OLEDs may replace LEDs especially in the general lighting and backlighting markets. Some OLEDs are already in the market.
	Principle of substitution: is substitution conceivable?	The extent of penetration is still unclear in the general lighting market.
	Opportunity for Europe	The development of OLED technology and products using them may create new market opportunities. In addition, greener solutions in the products and also in the manufacturing process compose possibilities.

4.3 Optical fibre

4.3.1 Optical fibre technologies and CRM dependence

Fibre optics transmits information; this technology enables the global data transmission underpinning the modern digital economy. A fibre optic system consists of three different parts; a transmitter unit converts an electrical signal to an optical signal, an optical fibre carries the light, and a receiver accepts the light or photons and converts them back into an electrical signal (Massa 2000, Jachetta 2007). An optical fibre is a flexible, hair-fine and transparent fibre made of pure silica or plastic. Optical fibres are used for the transmission of high volume data by sending light pulses along long distances. Optical fibres are also used over shorter distances for fixed broadband access and within data centres. The usage of optical fibres offers many advantages over the traditional copper wires used for the same purposes; for example they are the most energy efficient technique for transmitting high speed data (Weir *et al.* 2012).

The composition of optical fibre application is presented in Table 11.

Table 11: Structural composition of optical fibre.

Optical fibre cables	CRM content	Comments
Optical cable		
Cable core		
Sheath		
Strength members		
Water blocking material		
Coated optical fibre		
Glass fibre		
Dopant	Ge, (Nd, Er, Yb, Tm)	
Connectors		

An optical fibre consists of layers called core and cladding. It also has an additional coating surrounding the cladding, used for protecting the fibre from shocks etc. The transparent core is the actual light carrying medium, and the surrounding cladding allows total internal light reflection through the core part by providing the difference in refractive index. Glass fibres have a glass core and cladding. The glass used is either an ultra-pure and transparent SiO_2 or fused quartz. To achieve the demanded refraction index, impurities are added to the glass. (Jachetta 2007.) Germanium tetrachloride ($GeCl_4$) is converted to germanium dioxide (GeO_2) (Guberman 2012) and used as a dopant to enhance the optical properties (EPOW 2011, Villalba *et al.* 2012). Fibres made of plastic suffer from a limited performance. Fibres made of plastic can be either fully made of plastics or have a glass core and plastic cladding, and they do not have any coating around the cladding. (Jachetta 2007.) In addition, in optical glass fibre production platinum-rhodium vessels which tolerate high temperatures and do not react with glass are used (Butler *et al.* 2011). However, these PMG-based materials are used in the production process not in the application itself and therefore are not further examined in the supply chain analysis.

Apart from communication uses, optical fibres can also be used for sensors, fibre lasers and illumination applications (Peiró *et al.* 2011). Optical fibres are used for example as light guides in medical applications (used in places where ordinary light cannot be used), routing sunlight to other parts of buildings, decorative applications, remote sensing, imaging optics, microscopes and spectroscopy (Köhler *et al*. 2010). Optical glass fibres doped with some rare earth ions such as dysprosium (Dy), erbium (Er), neodymium (Nd), praseodymium (Pr), thulium (Tm) and ytterbium (Yb) are used in optical telecommunications and laser industries and also for the development of temperature sensors (Dussardier *et al.* 2008, Köhler *et al.* 2010).

A major application for critical raw material germanium is in fibre optics, accounting for around 30% of the overall consumption of germanium worldwide (Salazar & McNutt 2013). An optical fibre contains around 4 weight-% of germanium (Butterman & Jorgenson 2005). Approximately 1 g of germanium oxide is needed for the production of around 2.5 km of optical fibre (EPOW 2011). Erbium-doped fibre amplifiers are typically used for long-haul fibre connections. Dopant amounts are not published (Villalba *et al.* 2012).

The world's total production of germanium was around 100 – 120 tons in 2011, approximately 30% of that was recycled from electronic devices and coal fly ash (Guberman 2012). Over 60% of the germanium used during the manufacturing of most optical devices is routinely recycled as new scrap (Salazar & McNutt 2013). The pre-consumer recovery of germanium mostly comes from photovoltaic panels and fibre optics, while post-consumer recovery is very limited at present. A fibre optic cable contains relatively small amount of glass compared to cladding and coating layers, and as mentioned above, the amount of germanium is low, which may be the cause for the lack of post-consumer recycling (EPOW 2011). However, fibre optic cables are a potential option for post-consumer recycling (Buchert *et al.* 2009), and their recycling has already increased lately (Guberman 2012).

4.3.2 Analysis of CRM-related optical fibre market and supply chain

Economics

Optical fibre market

Based on the report by Integer Research (2011), the global demand for fibre optic cable was around 182 million fibre-km in 2010, and they estimated the demand for newly installed fibre to grow to 195 million fibre-km by 2011, whereas RnRMarketResearch.com (2013) assumed that the demand for optical fibre and cable was around 279 million core km in 2012.

Optical fibre and cable markets are an important part of the broader optical component markets. Nowadays, the major driver in the optical fibre and cable market is no longer regional or long-haul installations, but local deployments are dominating the markets. The global move towards broadband connection is resulting in increased optical fibre production, and this trend is expected to continue for at least a couple of years. Chafee (2012) forecasts the production to rise from 147 million fibre-kilometres in 2011 to 204 million by 2017, and the total price to grow from $1.32 billion (around €0.96 billion) to $1.79 billion (around €1.32 billion) (Table 2). (Chafee 2012.)

Table 12: Optical fibre production forecast (Chafee 2012, modified).

	2011	2012	2013	2014	2015	2016	2017
Optical fibre production (million km)	147	162	159	172	182	190	204
Unit price ($)	9.00	8.75	9.00	8.50	8.50	8.50	8.75
Total ($ billion)	1.32	1.42	1.43	1.46	1.55	1.62	1.79
Total fibre, cable and hardware ($ billion)	3.42	3.82	3.86	4.08	4.34	4.54	4.83

The leading countries in fibre optic cable production in 2011 were China (with around 75 million fibre-km production), USA (almost 35 million fibre-kilometres) and Japan (over 10 million fibre-kilometres), followed by France, Germany, India, South Korea, Spain, Italy, Vietnam, the UK, Turkey, Mexico, Belarus, Indonesia, Romania, Taiwan, Saudi Arabia, Norway and Finland, respectively. (Integer Research 2011.)

The major global market area for fibre optic cable so far has been China, with a share of more than 40% of all demand. Also the demand in USA, Japan, Germany, Netherlands and other advanced economies is expected to rise due to the building of new networks. New optical fibre lines are also being planned in emerging markets, such as Russia, Brazil, Bangladesh and Uzbekistan, and there are some significant expansion projects underway in India. The market growth in 2012 was assessed to come from North America and Western Europe, demand driven by Fibre-to-the-Home / Fibre-to-the-Cabinet solutions. It also seems that consumers are ready to pay more for fibre optic access to replace DSL (digital subscriber line) lines. (Integer Research 2011.)

Markets for different kind of specialized applications:

- Active optical cables (AOC) have transmitter and receiver built-in so connectors are not needed. AOC is a new market area that is growing fast, driven by supercomputers or high-performance computers, and data centres. The market size was around $50 million (€37 million) in 2011, with sales of around 160,000 units, but the markets are expected to triple by 2017.
- Ultra bend fibres and cables are more durable than basic optical fibres and cables. Ultra bend fibres are used in multiple dwelling units, for example in an entire city scale.
- Multimode fibres/specialized fibres. Multimode fibres have much larger diameter core (from 50 µm up to hundreds of micrometres) than single-mode fibres (8-9 µm). They are used in short-reach applications, such as for data centres and local area networking deployments and also in specialized imaging, illumination and medical applications. Multimode fibres had around 3-5% share of the total markets in 2011. Between 2011 and 2017 the amount is expected to rise to 5%, mainly originated from its growth potential in data centres. The production of these fibres is usually separated from single mode fibre operations. The amount of multimode fibres installed compared to the single mode fibres is higher in industrialized countries than in emerging nations. The price of multimode fibres is higher than single mode fibres. In 2011, around 6 million kilometres of multimode fibre was installed. The amount of multimode fibre used in specialized applications, such as illumination, military uses and sensing is forecast to remain quite stable from year to year. (Chafee 2012.)

<u>Position of EU in supply chain and main actors</u>

The supply chain of optical fibre consists of six main steps. In Figure 16 the supply chain of optical fibre is presented. The chain is focused on the optical fibre itself not on possible electronics or other components.

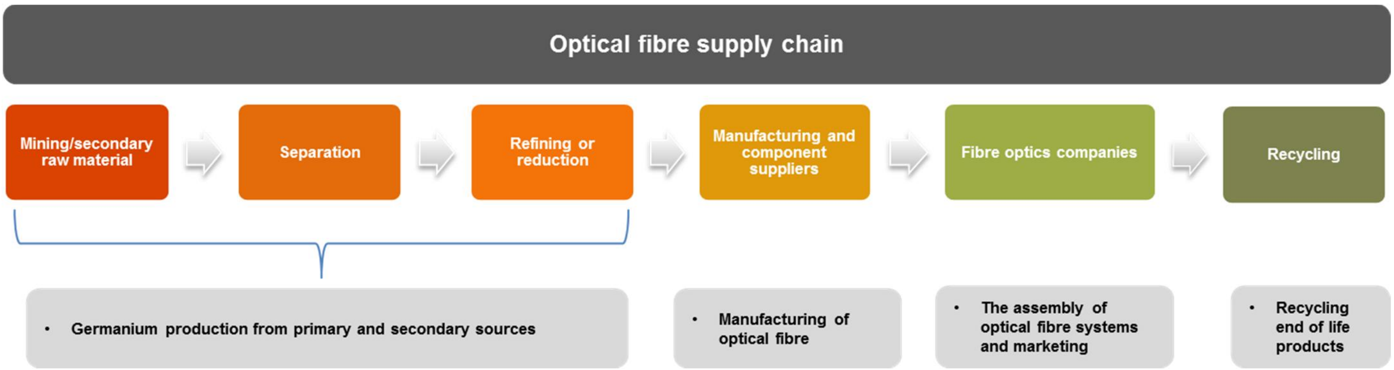


Figure 16: The supply chain of optical fibre.

In terms of optical fibre production the supply chain is rather simple and straight forward. The four main stages related to the CRM used are: germanium enrichment (from primary and secondary source) and refining stage, manufacturing of optical fibre, assembly of optical cable and possible recycling end of life products.

The main primary and secondary producers of germanium metal and components include China, Canada, Russia, Finland, the United States, and Belgium (Guberman 2012). CRM_InnoNet (2013b) also mentions Ukraine as the second largest germanium producer after China. Buchert *et al.* (2009) estimates the annual growth rate in germanium demand to be quite moderate; between 1.0% and 1.9% until 2020. Most imports to Europe originate from China or the United States (Halme *et al.* 2012). China is the leading producer of germanium metal and products in the world. In 2011, most of the around 80 to 100 tons of germanium metal and compounds produced in China originated from 5 to 6 companies in China. China used around 35 tons of the amounts produced and exported the rest. In Europe, Umicore in Belgium produces germanium tetrachloride for fibre optics. (Guberman 2012.)

Most optical fibre preform manufacturers are located in China, Japan, the US and Europe. Other countries producing optical fibres and cables mainly use imported preforms. The domestic optical fibre preform industry in China has developed rapidly resulting to lower dependence on import products, in 2012 their self-sufficiency was around 54%. Yangtze Optical Fibre and Cable Company Ltd. (YOFC), Jiangsu Hengtong Photoelectric Stock Co., Ltd. and Futong Group are currently the major preform manufacturers. YOFC is the largest optical preform manufacturer, with a current annual capacity of 1,500 tons and optical fibre manufacturing capacity of around 32 million core kilometres. The company has also set ambitious development targets. In 2012 the demand for optical fibre preform was around 9,200 tons. Mainly distributed in the Asia-Pacific region, China contributed almost 52% of the global total demand. (RnRMarketResearch.com 2013.)

China and India are the major suppliers of basic optical fibre cables, and in the field of more complex specialist fibres, North America is a strong producer (Butter *et al.* 2011). Corning Inc. and OFS are the two main optical fibre manufacturers in the world, but do have some serious competitors such as European based Prysmian Group (Draka). Corning and OFS are focused on every aspect of the optical fibre manufacturing process. Corning, for example, obtains around 30% of its revenues from optical fibre production and 70% from cable and accessories. Some active optical cable producers include Emcore Corp., Finisar Corp., TE Connectivity Ltd., AFL Telecommunications, Molex Inc. and Microsemi. OFS and Corning are also leaders in the ultra-bend fibre and cable area, although all leading producers have developed their own products. (Chaffee 2012.)

According to ARCEP (2010), France was the leading producer of optical fibres in Europe 2010, because it has two international optical fibre manufacturers located in the country. The Draka plant (currently owned by Prysmian Group) in Douvrin is the largest facility in Europe, and among the 5 to 6 biggest competitors globally. Draka produced around half of the company's global production, 50,000 fibre km/day. Draka Communications' Optical Fibre Division has factories on four continents, with the Douvrin plant as the main production site, and it supplied around 18% of the global fibre in 2010. The company also exports their European made products to China to meet the Asia's higher demand. ACOME has a production unit in Mortain, and the plant is the largest of company's four production sites. ACOME is among the four main producers of single mode optical fibre in Europe, with a production capacity of over 3 million cabled fibres annually. It reached sales of around €267 million in 2009, approximately 50% in the telecommunications market, and over 50% outside of France. (ARCEP 2010.)

Based on the data from Eurostat's centralized PRODCOM data base the production in EU as a value for *Optical fibre cables made up of individually sheathed fibres whether or not assembled with electric conductors or fitted with connector; Optical fibres and optical fibre bundles; Optical fibre cables (except those made up of individually sheathed fibres)* groups which contains optical fibre applications was approximately €1.4 billion in 2012. In addition, import to EU and export from EU for the same product group was approximately €0.6 and €0.7 billion respectively. (Eurostat 2012.)

A summary of main actors in optical fibre supply chain is presented in Figure 17.

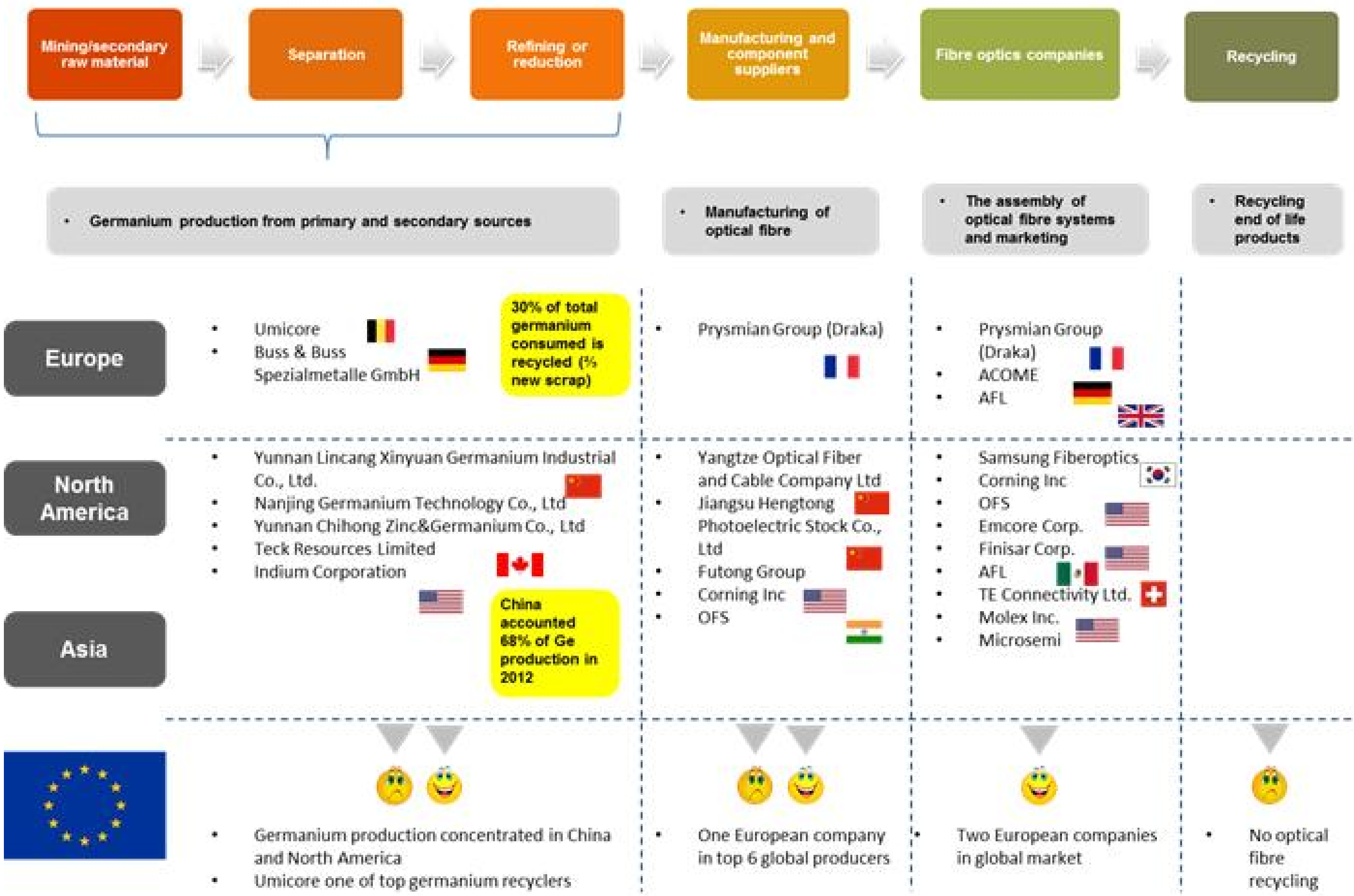


Figure 17: A summary of main actors in optical fibre supply chain.

<u>Jobs involved in EU</u>

Based on Eurostat's structural business statistics, the manufacture of fibre optic cables sector employed 9,500 people in 2010 within the EU. Germany employed approximately 1,800 people while the next largest employ countries were the United Kingdom and the Netherlands providing employment for approximately 1,500 people respectively. (Eurostat 2010b.)

<u>EUROSTAT data interpretation</u>

The quantitative supply chain analysis was carried out on data from Europe's PRODCOM database. More detailed information on the data and application composition can be found in Appendix 4 (Optical fibre data). The data from PRODCOM has been applied to produce supply chain illustration for production with largest producing countries in EU (Figure 18). **However, it is essential to understand that the shares/dimensions of different industries (box sizes) represent the production for the whole industry not only the share which is used in optical fibre production.**

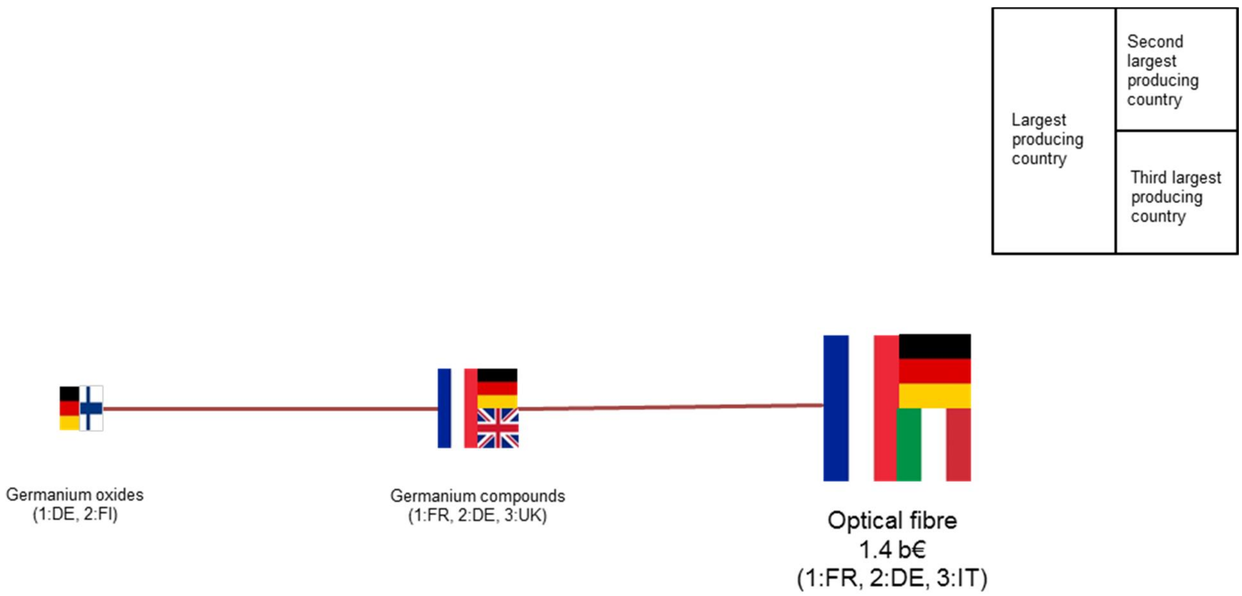


Figure 18: EU production of optical fibres and related (sub)-components and materials. Each box presents the total production value, not the value of components/materials which are used only in optical fibre applications. In addition, the largest EU producing countries are presented.

The production in the supply chain of optical fibre is focused at the end part of the chain. The production is mainly concentrated in Central Europe for the whole supply chain France as the largest optical fibre producer due to the Prysmian groups' (Draka) plants. Another significant producer country is Germany which iss the only country that can be found in each step of the chain.

The relation between production, import and export values for each step is presented in Figure 19.

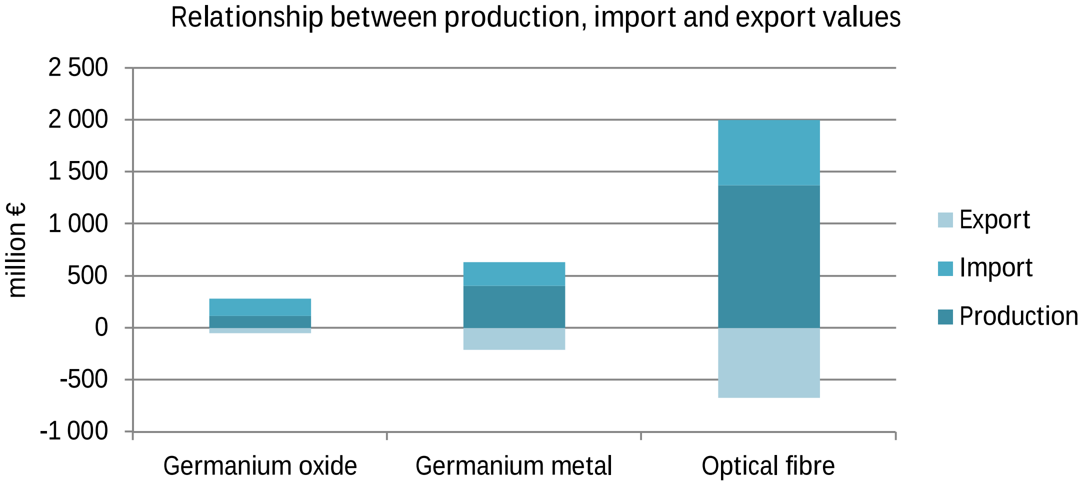


Figure 19: Relationship between production, import and export values for optical fibre, components and materials in Europe 2012. **Note** the values for components and materials represent the whole industry, not the share which is only used in optical fibre.

In Figure 19 production plus import, which are presented on the positive side of x-axis, represent the cumulative value of articles which are within Europe. Consequently, the value of export is on the negative side and expresses the value of articles which leaves Europe. Examining Figure 19 it can be noticed that production dominates the trade balance of the optical fibre. In addition, high import value and low export value indicates high consumption of optical fibre in Europe. As for germanium metal larger production than import value supports the business analysis where production of this metal from secondary sources in Europe had been identified. Germanium oxide is mainly imported.

Criticality

Essentiality of the role of CRM

Germanium is a significant metal for a number of future technologies, fibre optic cable production as one example (Schmidt 2012). Germanium is used as a dopant to enhance the optical properties of optical fibres, and some REE ions, such as neodymium, erbium, ytterbium, and thulium are used for doping optical fibres needed for example in laser and amplifier manufacturing. Germanium has unique and important optical properties that are especially useful for fibre optic cables; its index of refraction is high and optical dispersion low. A substitute for germanium may exist, but it would almost certainly lead to performance loss. Also erbium-doped glass fibres have an essential role in laser amplifier manufacturing. (Villalba *et al.* 2012.)

How will the vulnerability of the application evolve?

Short term market estimates forecast the overall demand for optical fibre products to remain strong at least in the next couple of years. However, the market studies discussed earlier do not assess long term situation, so the market vulnerability estimate for this time scale is hard to define. The vulnerability of optical fibre markets depends on the accessibility of the critical raw material germanium essential for manufacturing, because there are currently no respectable competitors for fibre optics based applications in the market. Limited germanium supply may hinder optical fibre production, if the supplier countries choose not to export raw materials outside their own markets or if the prices increase to excess.

The demand of germanium containing applications is expected to increase in the future and therefore the market situation is assessed to remain tight. Global germanium consumption is forecast to increase over the next few years. Germanium is a classical "hitch-hiker" metal, it is only available as a by-product of zinc ores, as they are chemically similar to each other. It is difficult to increase the production of these by-products metals, so another option is to boost the recovery and recycling of germanium. (Guberman 2012.) Fibre optics is one of the major end users of germanium (Salazar & McNutt 2013). Nowadays, there are not many opportunities for resource efficiency within fibre optics, because post-industrial recovery of germanium already exists, and post-consumer recovery is troublesome due to low volumes and concentrations of disperse waste streams. (EPOW 2011.) However, during the next two decades the availability of recycled germanium recovered from end-of-life products such as fibre optics is expected to become more common (Guberman 2012). Also the recovery of germanium from coal fly ash may become a more important germanium source in the future (Villalba 2012).

The potential of pre-consumer recycling may grow due to increasing production figures. Also post-consumer recycling together with well-organized pre-treatment and refining technologies will play an essential role. Because optical fibres contain only small amounts of germanium, recovering secondary germanium from optical fibre scrap is technically and economically challenging and complex. The EU Directives on Waste Electrical and Electronic Equipment (WEEE) is expected to make germanium recycling from old scrap more effective. It is also assumed that the uncertainty of the amount of global germanium reserves may act as a boosting agent for the development of enhanced recycling technologies. (Buchert *et al.* 2009.)

Available substitutes

Available substitution options for germanium in fibre optics are presented in CRM_InnoNet (2013b) report "Raw Material Profiles". As fibre optics is an important application for telecommunication and internet systems, there are on-going research and development projects focusing on better performance of this application. The research has also created some new technologies such as germanium-free photonic hollow fibres (Amezcua Correa 2009), fibres with tellurium layers, so called "OM2" or optical multi-mode fibres, and erbium-doped fibres (Christmann *et al.* 2009, cited by CRM_InnoNet 2013b). Also phosphorous-based doping (P_2O_5) is one possible option to avoid the use of germanium (Brown 1995, CEA 2013, cited by CRM_InnoNet 2013b).

Although possibilities for substitution of germanium in fibre optics exist, they either suffer from performance losses, are still in the research stage or their ability to fulfil the product requirements or industrialization capability is unclear. Also the high requisite production volume puts certain pressures on the substitution potential especially in the case of fibre optics. (CRM InnoNet 2013.)

Environmental

Impact on European policies in case of supply disruption

Optical fibres have replaced copper cables in data transmission. According to Weir *et al.* (2012) optical fibre manufacturing is a more energy efficient process than copper cable manufacturing, and optical fibres have a higher transmission capacity over almost all distances (from <1 m to 10,000 km). Optical fibres are the most power efficient method for transmitting high speed data. Copper cable manufacturing requires over a hundred times more energy than optical fibre manufacturing to achieving the equivalent data transmission capacity. However, it is noticeable that the increased demand for more transmission capacity may well lead to higher overall energy demand. Up until now the selection of optical transmission instead of other techniques has mainly been based on the capital costs to provide the required capacity, but the operational cost and in particular the energy cost and carbon footprint have recently become increasingly important. (Weir *et al.* 2012.) In the fault situation of manufacturing optical fibres the intentions to reach the current energy efficiency goals would become more difficult to achieve, due to the use of less efficient copper cables.

Innovation

Substitution activities already ongoing

Some of the technologies mentioned in the “Available substitutes” section can also be seen as substitution activities for traditional optical fibres. For example photonic crystal fibre technology is already commercially available and can offer numerous special characteristics that ordinary optical fibres are not able to exhibit. These fibres can be used for example in telecommunication, spectroscopy, biomedicine, metrology, imaging, industrial machining and military, and as the technology becomes a mainstream there will be even more applications using photonic crystal fibres. (Newport 2013.) However, according to CRM_InnoNet (2013b) all substitution options available have certain limitations and cannot effectively replace conventional optical fibres at the moment.

4.3.3 Optical fibre – business summary

A summary of business analysis is presented in Table 13.

Table 13: A qualitative summary of optical fibre application.

Dimension	Criterion	Required input
economic	Economic value of application or area	**In 2012, the value of optical fibre, cable and hardware production in EU was around €1.4 billon (Eurostat 2012).**
	Position of EU in entire supply chain	**Optical fibre production exists in Europe such as Prysman Group. As for germanium production, Umicore is a major player in Ge production from secondary raw materials.**
	Jobs involved in the EU	**<10,000 persons employed in 2010 at manufacture of fibre optic cables sector (Eurostat 2010b).** • **Two leading European producers Draka (Prysmian Group) and Acome had around 1,400 persons working in their plants in France in 2010 (ARCEP 2010).**
criticality	Essentiality of the role of CRM	• **Germanium is very significant for optical fibre production. According to Villalba *et al.* (2012) and Peiró *et al.* (2013) the substitution of germanium in optical fibres leads almost always in a lower performance.** • **Erbium-doped glass fibres have an essential role in the laser amplifier manufacturing.**
	How will the vulnerability of the application evolve (as a result of RM and market developments)?	**Optical fibre production should increase from 147 million kilometres of fibre in 2011 to 204 million in 2017 (Chaffee 2012), consequently markets do not seem very vulnerable in the short term. Limited germanium supply may effect to the optical fibre production, as the fibre optics industry is the major end user for germanium.**
	Available substitutes?	**See CRM_InnoNet (2013b) report "Raw Material Profiles" for substitution options.**
environmental	Impact on European policies in case of supply disruption	**Losses in energy efficiency.**
innovation	Substitution activities already ongoing? What is the status of that research?	**Some of the technologies mentioned in the "Available substitutes" section can also be seen as substitution activities for traditional optical fibres. For example photonic crystal fibre technology is already commercially available.**
	Principle of substitution: is substitution conceivable?	**Photonic crystal fibre technology can be divided into two categories:** • **Index guiding fibers have a solid core and photonic band gap** • **Air guiding fibers have periodic micro-structured elements and their core part is made of low index material (e.g. hollow core). (Newport 2013.)** **According to CRM_InnoNet (2013b) all substitution options available have certain limitations and cannot effectively replace conventional optical fibres at the moment.**
	Opportunity for Europe	**The development of new CRM free fibres or/and wireless technology which efficiency is on the same level as the current optical fibres' efficiency.**

4.4 Displays and screens

4.4.1 Display and screen technologies and CRM dependence

Displays and screens are used for presenting information in a visual form. Different kinds of display-based devices are widely used for communication, education as well as for entertainment purposes. Televisions, mobile phones and computers are everyday examples of display-based devices, but displays and screens are also used a wide range of other consumer products and in industrial, automotive and medical applications.

Examples of the most common display types include; cathode ray tube displays (CRT), liquid crystal displays (LCD), light-emitting diode displays (LED), electronic papers and plasma display panels (PDP). During recent years, flat panel displays have displaced CRT based displays in the market. LCD technology is the most prevailing flat panel display technology at the moment, but OLED and e-paper technologies are also beginning to penetrate the market (Weir *et al.* 2012).

This application report focuses mainly on LCD flat panel displays, because:

- Plasma displays have only a minor role in current market (Böni & Widmer 2011) and besides they are only significantly used in the TV sector (Buchert *et al.* 2012)
- LED displays (or so called true-LEDs, as distinct from LED-backlit LCD displays) are mostly used in different types of signs and billboards
- OLED and e-paper technologies are classified as emerging technologies.

An LCD technology exploits the light modulating properties of liquid crystals. It is a passive display technology, as liquid crystals do not directly emit light. The advantages of LCD include its energy efficiency and small size. Nowadays, most LCD displays use LED backlight instead of traditional cold-cathode fluorescent lamp (CCFL) backlight (DisplaySearch 2009, 2011). An LCD display consists of a plastic housing, front and back frames, an LCD module, optical films, a backlight unit (uses either CCFL or LED), power supply and controller units, a rear cover, loudspeakers, and a stand. There is also one or more printed circuit board equipped with connectors and electronic components in a display device.

A LCD module comprises two glass substrates with polarization filters on their outer sides, used for polarizing the unpolarized light, and a liquid crystal solution placed between them. On the inner sides of the substrates there are thin-film transistors on one glass substrate and colour filters on the other. On both sides of the liquid crystal solution are transparent conductive electrodes and orientation films, both plated onto the filters. These conductive electrodes are made from indium-tin oxide (ITO). (Lee & Cooper 2008.)

Table 14: A structural composition of an LCD display.

Displays	CRM content	Comments
LCD display		
Housing		
Frame		
LCD module		
Glass substrate		
Liquid crystal		
Conductive electrodes		
ITO	In	
Orientation films		
Color filter		
Films		
Backlight		Backlight can be produced either by cold cathode fluorecent lamp or LED
Cold cathode fluorescent lamp		
Phosphors	Ce, Y, Tb, La, Eu, Gd	
LED		
Semiconductor die	In, Ga	
Phosphors	Ce, Y, Tb, La, Eu, Gd	
Electronics		
Printed circuit boards		
Plating	Pd	Not very common to use Pd as plating, generally Ni/Cu and Au are used
Components		
Capacitors	Ta, Pd, Nd	
Resistors	Ta, Ru	
Semiconductors	Ga, Ge, In, Sb	
Transistors	Ga, Ge	
Electronic and integrated circuits		
Capacitors	Ta, Pd, Nd	
Resistors	Ta, Ru	
Semiconductors	Ga, Ge, In, Sb	
Transistors	Ga, Ge	
Connectors	Pd, Ru, Be	
Cables		
Loudspeakers		
Magnets	Nd	

The main use of indium, around 74-80%, is in flat panel displays (EPOW 2011, Böni & Widmer 2011). According to Böni & Widmer (2011) the flat panel display industries use more than 50% of primary, and up to 80% of all indium available. The indium supply from primary resources was around 670 tons in 2012; however more indium is produced secondarily from recycling. It is an ideal material for thin-layer electrodes due to its good qualities, such as transparency, metal-like conductivity and heat-resistance (Buchert *et al.* 2012, Böni & Widmer 2011). However, as a result of a dissipative use of indium in the LCD manufacturing process, only about 15% of the ITO source material will end up in the actual product (EPOW 2011). Thin films made of ITO are widely used in LCD monitors, televisions, notebooks, mobile phones (Buchert 2009) and other flat panel devices.

According to CRM_InnoNet (2013b) ITO layers consist of 90% In_2O_3 and 10% SnO_2, corresponding to a percent by weight of indium of 75%. In the literature, estimations about indium content and layer thicknesses of ITO for LCDs vary significantly, as shown in .

Table 15. Böni & Widmer (2011) estimated the average indium content for different kind of flat panel display types, with assumed ITO layer thickness of 125 nm; for LCDs indium content corresponds to 234 mg/m^2, and since OLED and plasma displays only need one layer of ITO instead of two layers needed in LCD, their indium content equals to 117 mg indium/m^2.

Table 15: Indium content in LCDs (Bömi & Widmer 2011, Buchert *et al.* 2012, modified).

	mg ITO/m^2	nm/layer	mg In/m^2
Becker *et al.* (2003)	192	80	150
Becker *et al.* (2003)	240	100	187
Socolof *et al.* (2005)	7176	2990	5597
ISI (2009)	4000	1667	3120
Martin (2009)	700	292	546
Bogdanski (2009)	72	30	56
Bogdanski (2009)	192	80	150
Böni & Widmer (2011)	300	125	234
Buchert *et al.* (2012)	897	-	700

Based on different studies (also including the above-mentioned study of Böni & Widmer's (2011)), Buchert *et al.* (2012) analysed the estimated mean content of indium for the selected display devices (Table 16).

Table 16: Mean indium content of different display devices, with assumed mean indium value of 700 mg/m^2 for LCD displays (Buchert *et al. 2012*, modified).

	Mean screen area [cm^2]	Mean indium content / device [mg]
Notebooks	552	39
Computer monitors	1,126	79
Televisions	3,626	254

Also rare earth metals are used in displays, as a phosphor material. Depending on the technique used, REEs are either used in the background lighting (LCD technology) or in the displays themselves (plasma and OLED technologies). (Buchert *et al.* 2012.) Each different technology uses different types and compositions of phosphors; the phosphor composition used depends on the colour requirements of the end product (Peiró *et al.* 2011). LCD displays with LED background illumination also contain indium in their semiconductor dies (see section 4.2). Only general data is available on the use of REEs in displays as all more precise composition data is usually confidential. However, Buchert *et al.* (2012) also assessed these approximate contents, and the results of their analysis are seen in Table 17. In their study, they estimated the average amount of white LEDs used in a LCD television, computer monitor and notebook monitor to be 150, 100, and 50, respectively. In addition, in the glass plate production polishing agent/slurry containing cerium and PGM (platinum and rhodium) linings in the moulds are used. However, these materials are used in the production process not in the application itself and therefore are not further examined in the supply chain analysis.

Table 17: Mean content of critical raw materials per LCD television, PC monitor and notebook monitor (Buchert *et al.* 2012, modified).

Metal	Content / LCD TV [mg]		Content / LCD PC monitor [mg]		Content / LCD notebook monitor [mg]		Occurrence
	CCFL	LED	CCFL	LED	CCFL	LED	
Indium	254	258	79	82	39	40	ITO + background illumination (100%)
Yttrium	110	4.80	16	3.20	1.80	1.60	Background illumination (100%)
Europium	8.10	0.09	1.20	0.06	0.13	0.03	Background illumination (100%)
Lanthanum	6.80	0.00	1.00	0.00	0.11	0.00	CCFL background illumination (100%)
Cerium	4.50	0.30	0.68	0.20	0.08	0.10	Background illumination (100%)
Terbium	2.30	0.00	0.34	0.00	0.04	0.00	CCFL background illumination (100%)
Gallium	0.00	4.90	0.00	3.30	0.00	1.60	LED background illumination (100%)
Gadolinium	0.63	2.30	0.10	1.50	0.01	0.75	Background illumination (100%)
Praseodynium	<0.13	0.00	<0.019	0.00	<0.003	0.00	CCFL background illumination (100%)
Palladium	44	44	40	40	4	4	PCB and contacts (100%) Notebook: Display PCB
Tantalum	-	-	-	-	170	170	Capacitors on PCBs (10%) Note: only motherboards Ta share excluded, incudes all other PCBs in notebook

Buchert *et al.* (2012) estimated the amount of CRMs used in notebook PCBs. Tantalum, used in high capacity capacitors is of particular importance. Table 17 also represents the contents of palladium and tantalum used in printed circuit boards. Tantalum contents in notebook monitors are just rough estimates from the estimated overall content of Ta in notebooks (1,700 mg, from which capacitors on the motherboard account for 90%, and capacitors on other PCBs 10%). Thus the estimated content of tantalum (170 mg in other PCBs), may also include other than display PCBs. However, tantalum capacitors may be partially substituted by other capacitors, and that leads to the estimate that Ta content of notebooks can vary remarkable between the manufacturing year and device generation (Buchert *et al.* 2012). The electronic components in display PCBs may also contain other CRMs than presented here (see

Table 14), however no specific information about the amounts of these components is available. A detailed analysis of assembled printed circuit boards is presented in section 4.6.

Some devices, such as televisions, also have permanent magnet based loudspeakers, containing neodymium (Nd) (See MRI section 4.1 for general information about permanent magnets). However, there is no specific information available on the usage of these magnets in TV loudspeakers or their unit weights (Buchert *et al.* 2012).

4.4.2 Analysis of CRM-related displays and screens market and supply chain

Economics

Due to the lack of reported global and European production data on backlighting and flat panel displays, the focus on this economic analysis is on revenues and unit shipments. The shipment is a logistic term for the quantity of products which have been shipped to or from somewhere.

Flat panel display market, focus on LCD

The market leading LCD industry is defined by rapid technological advances and new products and applications; increased use of the LCD technology in larger size TVs is expected to drive market growth. In 2012, the total LCD market had revenue of $94.16 billion (around €70 billion) and 1,691 million unit shipments. With a CAGR of 31% the market is expected to grow to $362.87 billion (around €268.7 billion) by 2019, with around 4,200 million unit shipments. In 2012, South Korea accounted for almost 45% of the global market, with revenues of $42.12 billion (approximately €30.79 billion) and unit shipments of around 710 million, when North America's and Europe's combined market share was only around 1% or $0.94 billion in revenues (around €0.69 billion) with the shipments of 34 million. The expected CAGR of 7.5% leads the market to revenues of $1.35 billion (€1.00 billion) by 2019, with 84 million unit shipments. South Korea will strengthen its position to a share of over 50% of the market with the revenues of over $190 billion (€138.9 billion) and shipments of 1,763 million (CAGR = 22.7%) in 2019 (Figure 20). (Frost & Sullivan 2013c.)

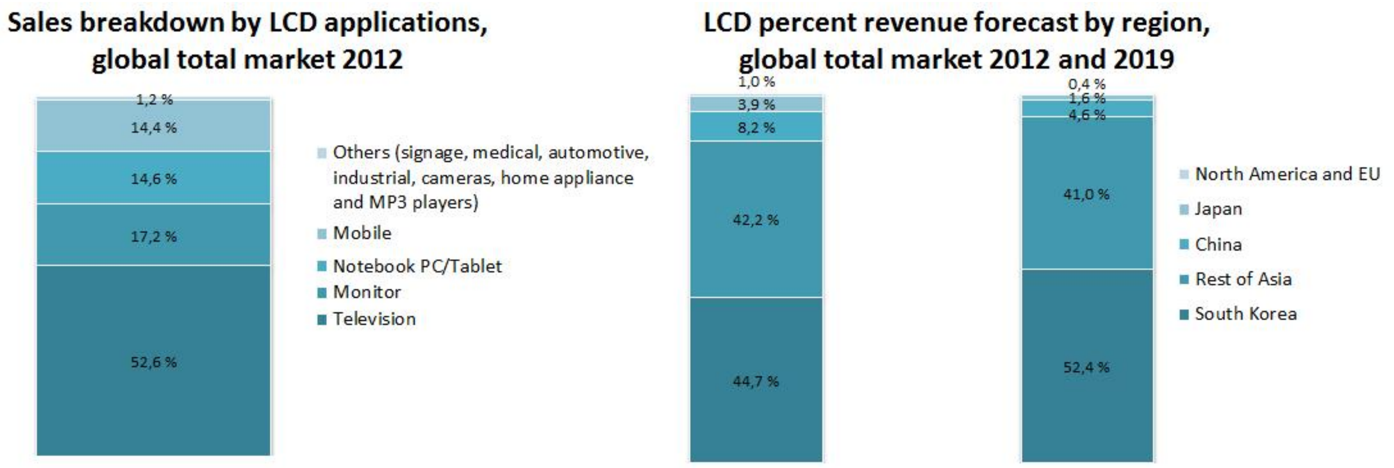


Figure 20: Percent of global LCD sales by application and region in total markets, 2012 (Frost & Sullivan 2013c, modified).

According to DisplaySearch (2012) around 245 million televisions shipments were done globally in 2012 and the shipments will rise to around 275 million units by 2014. LCD televisions had a share of around 88% of all global televisions shipments in 2012 and by 2015 this share is likely to increase to 97% of the overall unit demand. On the other hand, plasma TV shipments are expected to fall to about 5% of total shipments (DisplaySearch 2012). However, it is notable that the forecasts by different authors are not very consistent (Figure 21). LCD TVs with LED backlighting dominate the market; their share has already reached 85-95% (McKinsey & Company 2011, Wolfgram 2013). In 2016 OLED technology is expected to be the only competing technology in the market, whereas LCD TVs with CCFL background illumination and plasma TVs will lose their current market shares (DisplaySearch 2012). TV shipments in Eastern European emerging markets are growing, while in Japan and Western Europe the shipments are assessed to decline through 2015 due to saturated market situation and completed digital transitions in many countries (IMS Research 2011).

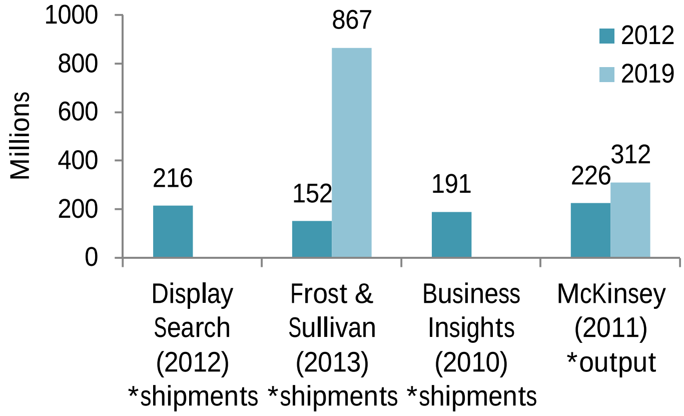


Figure 21: Unit shipment//output (quantity of products manufactured) forecasts for LCD TVs by different authors.

The fast penetration of LED backlighting technology is also seen in the computer monitor markets. According to McKinsey & Company (2011), in 2010 only 24% of LCD monitors had LED backlighting and the rest were CCFL backlit, whereas by 2012 the situation had reversed; LED penetration rate accounted for 75%, and CCLF's rate for 25%. OLEDs are also emerging into the computer monitor markets. By the year 2020, OLED technology is expected to have 30% market penetration rate, the remaining 70% comprising LEDs, with estimated overall model outputs of 277 million. (McKinsey & Company 2011.)

Figure 22 presents the revenue and unit shipment forecasts for different LCD segments, based on analysis by Frost & Sullivan (2013). In terms of revenues, LCD TVs are the major driver of the markets. This market has grown vigorously during the recent years, and is expected to continue its growth in the near future. In terms of LCD TV shipments, they are predicted to rise from 152 to 867 million units between 2012 and 2019, achieving revenues of almost $276 billion (around €204 billion) in 2019. For other applications the revenue based growth is much more moderate. On the other hand, in terms of unit shipments mobile phones and other portable devices are forecast to maintain their major position. (Frost & Sullivan 2013c.)

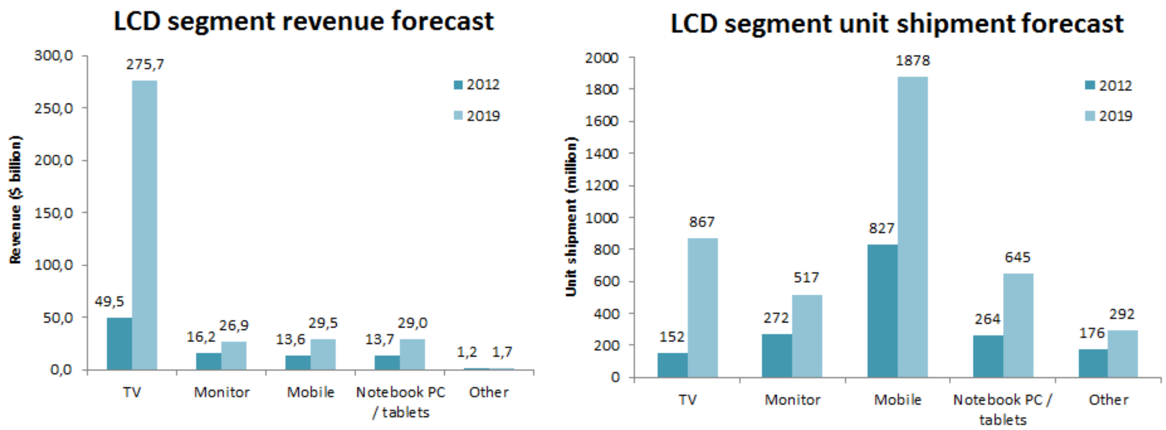


Figure 22: LCD segment revenue and unit shipment forecasts (Frost & Sullivan 2013c, modified).

OLED display revenues will grow from around $4 billion (around €2.95 billion) in 2011, to about $35 (around €25.8 billion) billion by 2018, with a compounded annual growth rate (CAGR) of around 40% (Colegrove 2012). Also the market for e-papers is forecast to reach €3 billion by 2016 (NanoMarkets 2009, cited by Weir *et al.* 2012).

LED display and lighting markets, focus on backlighting

Frost & Sullivan (2013b) categorised the LED display and lighting market into three segments:

- Backlighting: This segment contains the use of LEDs in notebook computers, TVs and monitors. Backlighting segment had the highest sales share in 2011, around 51%.
- Mobile segment: Includes the use of LEDs in LCD backlights, keyboard backlighting, indicator light and flash lamps. Had a share of 29% of sales in 2011.
- Automotive lighting: Consists of LEDs used in exterior lighting (headlights and tail lights) and interior lighting (dashboard, door and ambient lighting). Held a share of almost 20% of the LED display and lighting market in 2011. (Frost & Sullivan 2013b.)

The backlighting and mobile segments can be seen as parts of display and screen application in the ICT and electronics sector, automotive lighting is not discussed further in this report. According to Frost & Sullivan (2013b), the global market for LEDs in backlighting and mobile segments had revenue of $3.48 billion (approximately €2.55 billion) in 2011, and the market is expected to reach $7.85 billion (approximately €5.76 billion) in 2016. Percentage values in 2016 are assumed to be for LEDs in backlighting 72% and for mobile 28%. (Frost & Sullivan 2013b.)

In the total LED lighting market (i.e. all LED applications which includes LEDs), backlighting is the most important segment at the moment, and it is expected that the share of LEDs in the backlighting will soon gain 100% (Figure 9). However, it is assumed that the display technology will soon move from LCD TVs to OLED TVs, in which backlighting is not used at all, and also the use of brighter LEDs leads to a decreasing number of LEDs required in the displays. As a result the backlighting market (excluding OLED displays) is likely to decline to around half of its current value by 2020. (McKinsey & Company 2011, 2012.) More information about LEDs is presented in section 4.2. “LED lighting”.

Taiwan, Korea and China are the most important Asian countries in the overall LED display and lighting markets. Asia had market revenue of $2.79 billion (around €2.05 billion) in LEDs in backlighting and mobile segments in 2011. North-America is the second largest market area, followed by Europe. It is predicted that Asia will strengthen its position as market leader at least in the short term in comparison to the other countries, and market revenue of $6.36 billion (approximately €4.66 billion) is expected to be reached in 2016. However, the annual revenue growth rate is expected to decrease after the backlighting segment hits its saturation over the next few years. The European market for LEDs in backlighting and mobile segment had $0.14 billion (approximately €0.10 billion) in revenue in 2011, and the market is expected to achieve $0.23 billion (approximately €0.6 billion) in 2016. (Frost & Sullivan 2013b.)

ITO market

Indium-tin oxide accounted for 93% of the total market for transparent conductors in 2012 with a market value of more than $1.5 billion (around €1.1 billion), mainly because of its wide-ranging use in flat panel and touch screen displays and photovoltaics (Thiele 2012). Due to the criticality of indium, new research projects for the replacement of conducting films are in progress, and the market share of ITO is expected to decrease to 79.4% on a unit basis by 2016. However, due to the high price of indium, on a revenue basis ITO is expected to maintain its share of 96.0% in 2016. (Semiconductor Packaging News 2011.)

Position of EU in supply chain and main actors

The supply chain of a display consists of six steps (Figure 23). The chain includes both backlight and electrode production. In addition, electronic component and permanent magnet production are included in the entire supply chain which is presented in Figure 26.

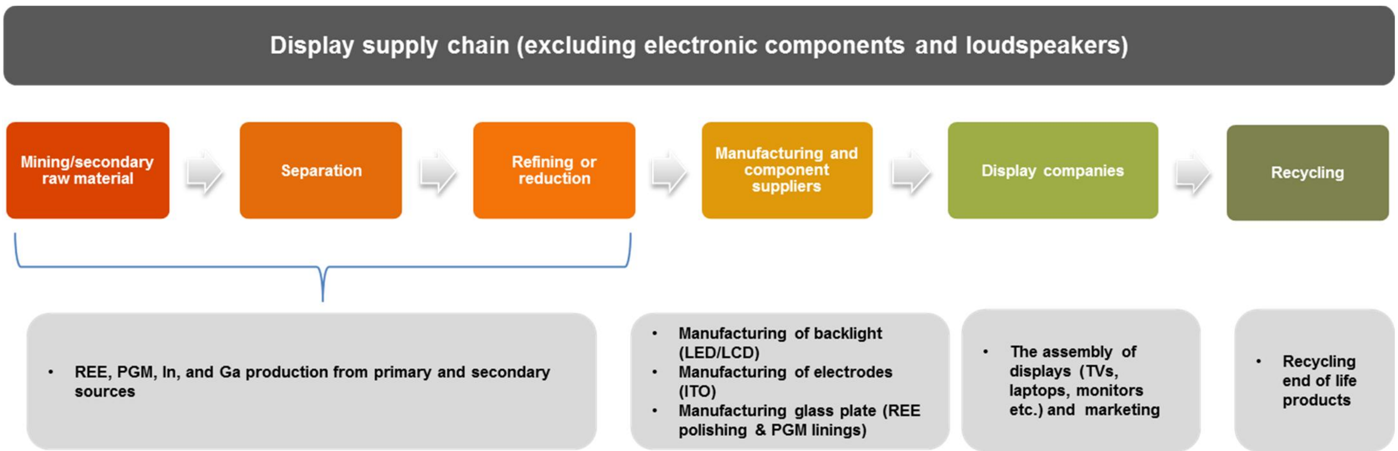


Figure 23: The supply chain of display application, excluding electronic components and loudspeakers.

The first three steps in the supply chain refer to the production and refining of CRM (from primary or secondary sources) for the component suppliers, which in this case are backlight and electrode producers. In addition, in the glass plate production polishing agent/slurry containing cerium and PGM (platinum and rhodium) linings in the moulds are used. The component suppliers produce components for the end producer which includes both assembly and marketing of the display. Finally, the sixth step in the supply chain is the recycling of the end of life product.

The main indium producers include China, Canada, South Korea, Japan and Belgium. The global consumption of indium in 2011 was over 1,800 tons, of which around 60% was consumed in Japan. (Salazar & McNutt 2012, 2013.) Asia is the leading region producing and consuming indium-tin oxide. There is also ITO production in Canada, Peru and Belgium. (Transparency Market Research 2012.)

Belgium based Umicore is one of the ITO producers located in Europe. Also Japanese company Nitto Denko has a production plant located in the Czech Republic.

The production of LEDs for display and lighting is mainly located outside Europe (Note: the automotive lighting segment is also included in the following figures). The number of companies in the market is around 1,000 globally. The major market participants are Samsung LED, Nichia, Cree, Tyntec and Epistar, with the top five companies having 44% share. The market share of the 10 most important competitors is about 69%. Samsung LED is the market leader with 13.5% share. Asia dominates also the mobile markets for LEDs. The leading manufacturers of white LEDs used in mobile phones, are Nichia, Toyoda Gosei, Cree, Philips Lumileds, and Osram. (Frost & Sullivan 2013b).

Europe is the largest end-user market for flat panel displays currently, but European display supply chain can be described as fragmented and small (Weir *et al.* 2012). Although the European research base is strong and it has connections to Asian companies, no high volume production is located in Europe by European companies (Butter *et al.* 2011). However, several international companies, such as Samsung, Sharp and LG have their production/assembly/research facilities located in Europe. According to DFF (2009) large TV set assembly businesses were located in the Czech Republic, Hungary, Poland and Slovakia in 2009, with the result that almost all flat panel TVs in the European market were also made in the the EU.

Due to the high capital investments required for flat panel display production facilities (Weir *et al.* 2012) the actual production of many consumer orientated, large output displays is dominated by Asian based companies. However, there is some significant production of low-volume high performance displays in Europe, such as healthcare, security/defence, automotive and other non-consumer display production. Germany and the United Kingdom are especially represented in these markets. (Butter *et al.* 2011.) For example, Belgian based Barco manufactures medical displays among other display products (Barco 2013). Also new concepts for niche markets and emerging technologies, such as near eye displays (Butter *et al.* 2011.), OLED based flexible displays, pico projectors, printed organic backplanes and electro-wetting displays are important for European companies. Europe has many companies within the display supply chain, mainly in the production of base materials for components and process equipment area, without any significant panel or original equipment manufacturers. Europe has also strong research and development capability in the area of display devices (such as OLEDs and e-displays), material supply/verification and manufacturing processes. (Weir *et al.* 2012.)

There are around 150 competitors in the LCD display markets globally. LG Display is the current market leader; holding a share of almost 25% of the market, with revenues of $23.44 billion (around €17.35 billion) in 2012. LG Display produces laptop and notebook computer screens, desktop PC monitors, TV sets, wireless handsets, and many different kinds of other applications for automotive navigation, consumer electronics, avionics, instrumentation, and medical equipment. Samsung Electronics (which focuses more on high-end LCD user applications) and Chimei Innolux are the other major market participants, with 22% and 18% shares and $20.71 (around €15.27 billion) and $17.13 billion (around €12.63 billion) revenues, respectively. In the LCD market, the top 5 competitors had almost an 85% market share in 2012, and among the ten biggest participants this share was over 94% (Figure 24). The LCD markets can be characterized as consolidated, however the markets are also volatile and nascent, and this means that rapid shifts in the market situation are possible. (Frost & Sullivan 2013c.)

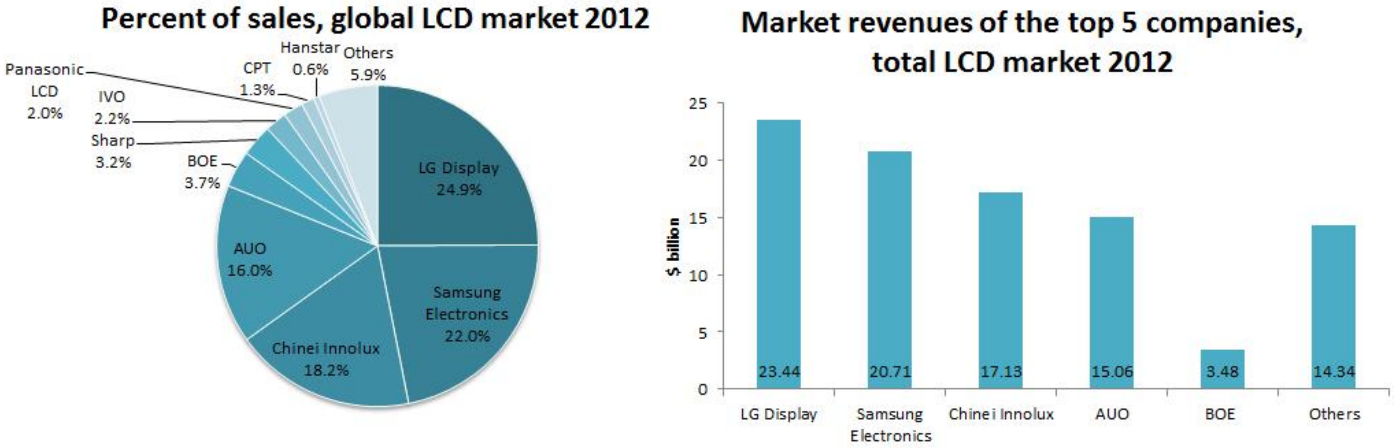


Figure 24: The main competitors in the global LCD markets (Frost & Sullivan 2013c, modified).

South Korea has the leading position in LCD panel production markets, with two major market participants LG Displays and Samsung Electronics, followed by Taiwan, China and Japan. The South Korean market is small in per capita basis when compared to the North American and European markets, but its growth in demand and especially in production has been fast. Extensive capital investments made for the next-generation fabrication plants are behind the fast growth which occurred in Korea. Taiwan has many new competitors in the LCD market field. Taiwanese manufacturers are mainly categorized as technology followers, although some LCD producers have also invested for the latest generation plants. Taiwanese producers are able to competitively manufacture large volumes of LCD displays. In Western Europe, the markets are moving towards a more developed stage of growth from the earlier nascent stage. The markets in Central and Eastern Europe, such as Poland, Hungary and the Czech Republic, contribute to LCD panel production. In Hungary, the current situation enables the production (increased local demand, establishment of contract manufacturing, established supplier networks and logistics, and skilled labor), and the same trend is also seen in the Czech Republic (Frost & Sullivan 2013c.)

Based on the data from Eurostat's centralized PRODCOM data base the production in Europe as a value for all groups including displays is presented in Table 18 (Eurostat 2012).

Table 18: PRODCOM data for display group.

PRODCOM group	Production (M€)	Import (M€)	Export (M€)
Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c	9,000	2,300	2,000
Colour television projection equipment	3,800	5	19
Indicator panels incorporating liquid crystal display (LCD)	230	970	130
Indicator panels incorporating light emitting diodes (LED)	350	260	150
Tuner blocks for CTV/VCR and cable TV receiver units (colour video tuners) (excluding those which isolate high-frequency television signals)	360	1,900	170
Monitors and projectors, principally used in an automatic data processing system	180	2,600	640
Electrical apparatus for sound or visual signalling, n.e.c.	480	310	280
Flat panel video monitor LCD or plasma , etc. without tuner (colour video monitors) (excluding cathode-ray tube)	750	660	320
Total (Sum)	15,000	9,000	3,700

The display application includes seven different PRODCOM groups from which *Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c. and Colour television projection equipment* groups composed around 85% of the total production value which was approximately €15 billion. As for indicator panels (both LCD and LED) the share of total production was only around 4%. The import was dominated by *Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c; Tuner blocks for CTV/VCR and cable TV receiver units (colour video tuners) (excluding those which isolate high-frequency television signals) and Monitors and projectors, principally used in an automatic data processing system* groups composing around 75% of total import value which was approximately €9.0 billion. The total export value (€3.7 billion) was dominated by *Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c;* group with a 55% share. The value for displays used in televisions, monitors and panels only is less due to the other products included in the PRODCOM groups. However, more specific information on the display distribution between these groups could not be found. A summary of the main actors and Europe's position in display supply chain is presented in Figure 25.

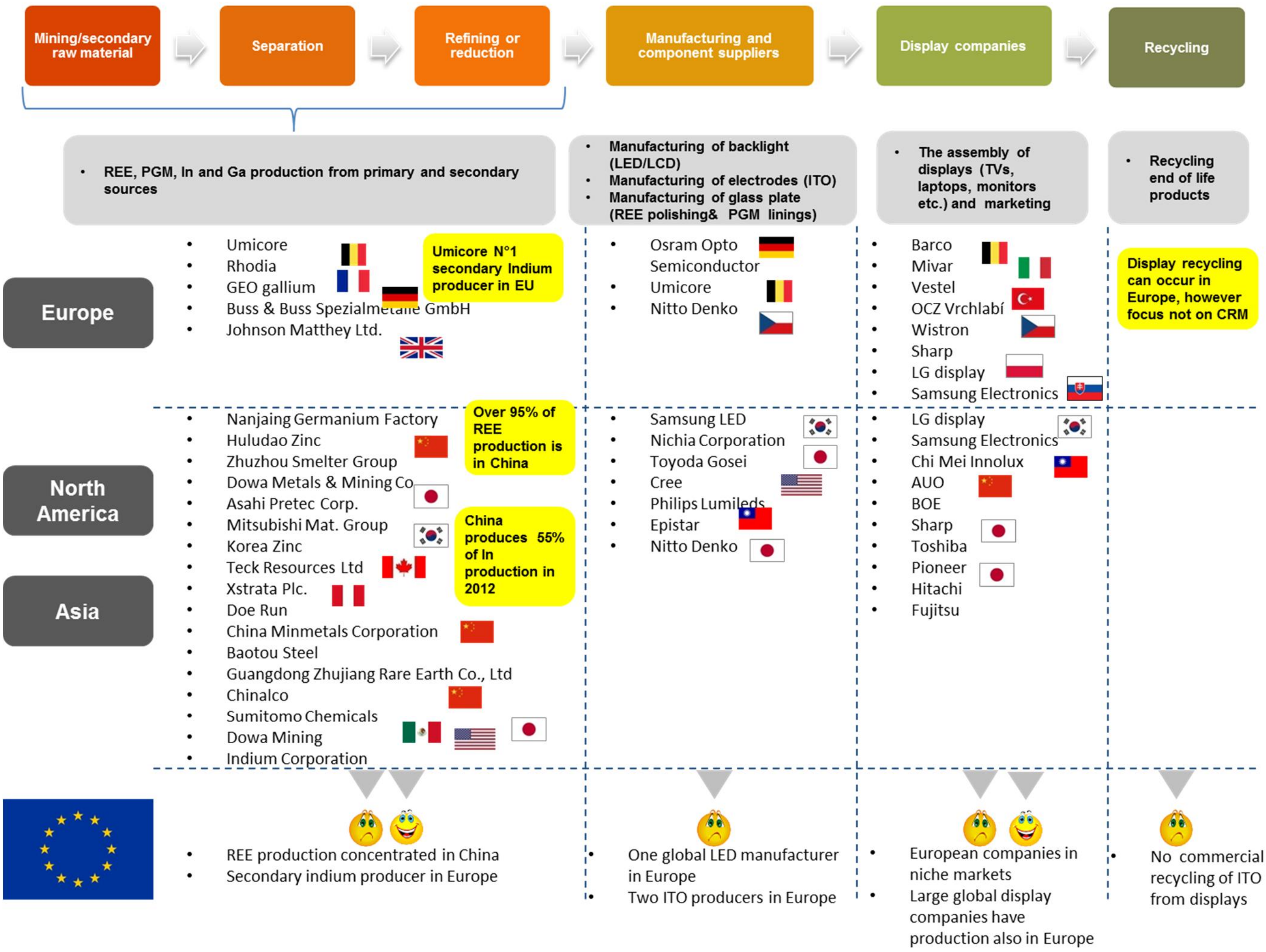


Figure 25: A summary of main actors and Europe's position in display supply chain.

Jobs involved in EU

Based on Eurostat's structural business statistics, manufacture of consumer electronics sector (including: *Monitors and projectors, principally used in an automatic data processing system; Tuner blocks for CTV/VCR and cable TV receiver units (colour video tuners) (excluding those which isolate high-frequency television signals); Colour television projection equipment; Flat panel video monitor LCD or plasma , etc. without tuner (colour video monitors) (excluding cathode-ray tube) and Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c.* PRODCOM groups) employed 82,000 people in 2010 within Europe. Germany employed approximately 14,000 people while the next largest employing countries were Poland and Slovakia providing employment for approximately 12,000 and 7,500 people respectively. In addition, manufacture of other electrical equipment sector (including: *Indicator panels incorporating liquid crystal display (LCD); Indicator panels incorporating light emitting diodes (LED) and Electrical apparatus for sound or visual signalling, n.e.c.* PRODCOM groups) employed approximately 180,000 persons in 2010 within Europe. Germany provided employment for over 50,000 people while Italy as second largest employing country employed approximately 34,000 people. (Eurostat 2010b.)

EUROSTAT data interpretation

The quantitative supply chain analysis was carried out on data from Europe's PRODCOM database. More detailed information on the data and application composition can be found in Appendix 5 (Display data). The data from PRODCOM has been applied to produce supply chain illustration for production with largest producing countries in Europe (Figure 26). **However, it is essential to understand that the shares/dimensions of different industries (box sizes) represent the production for the whole industry not only the share which is used in display production.**

Based on data from Eurostat (PRODCOM), production is strongly focused on the end production of application. However, the end application included all kind of displays, monitors and projection equipment and therefore ending to higher value than only displays would generate. As in the MRI and LED lighting application the production value of electronic circuit is significant as well as production of platinum group metals.

The largest producing country for end product is Poland (due to the Sharp's LCD factory and LG's production plant) followed by the Czech Republic. For almost all other components Germany is the largest producing country. Other significant component producers are Italy and France. The UK has platinum group metals production with companies such as Johnson Matthey Ltd.

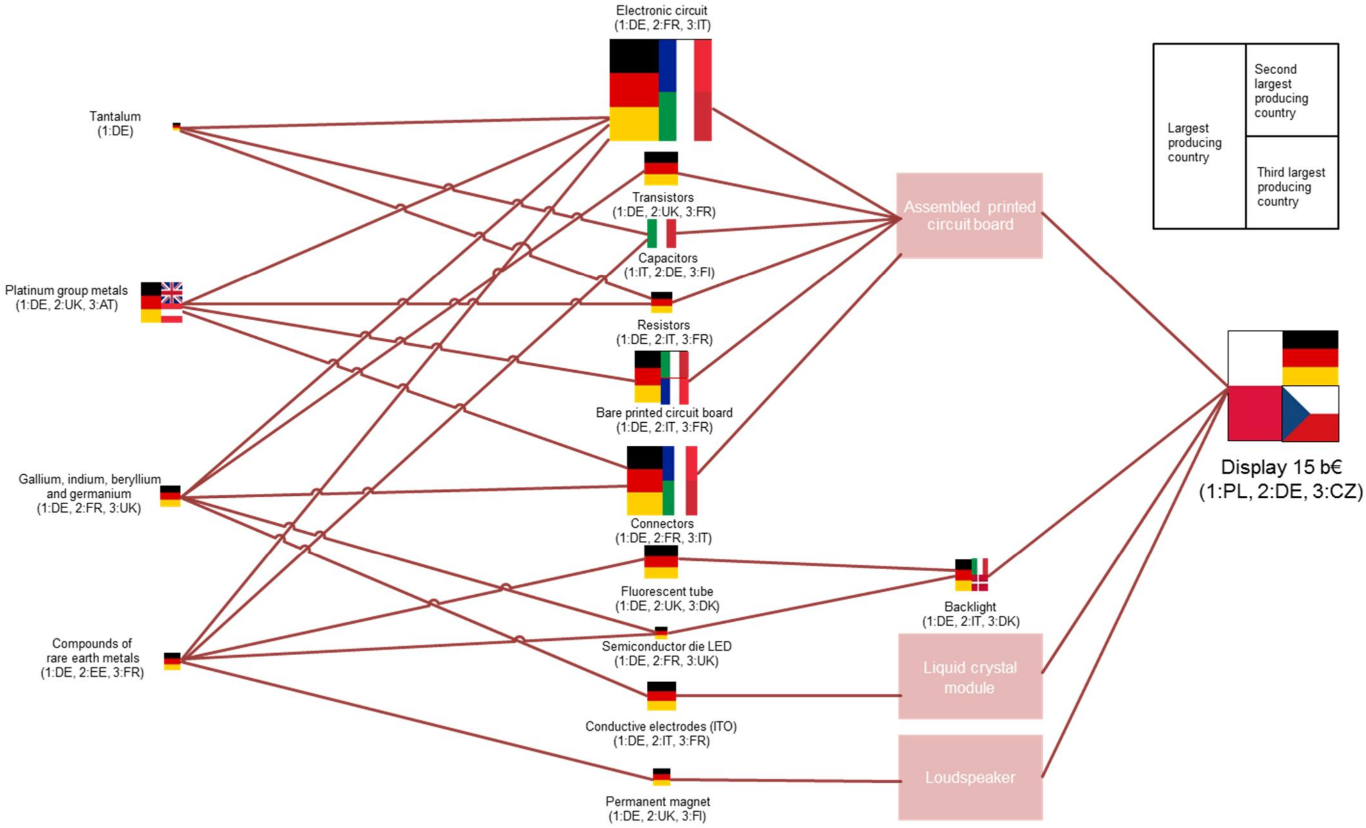


Figure 26: EU production of displays and screens and related (sub)-components and materials. (Sub)-components in pink boxes have no corresponding PRODCOM group and therefore no statistically defined value and are included for completeness. Each box presents the total production value, not the value of components/materials which are used only in display applications. In addition, the largest EU producing countries are presented.

In Figure 27 the relationship between production, import and export values for all components, materials and end application is presented. Note the values for components and materials represent the entire industry, not just the share used in displays. Production plus import, which are presented on the positive side of x-axis in Figure 27, represent the cumulative value of articles which are within Europe. Consequently, the value of export is on the negative side and expresses the value of articles which leaves Europe.

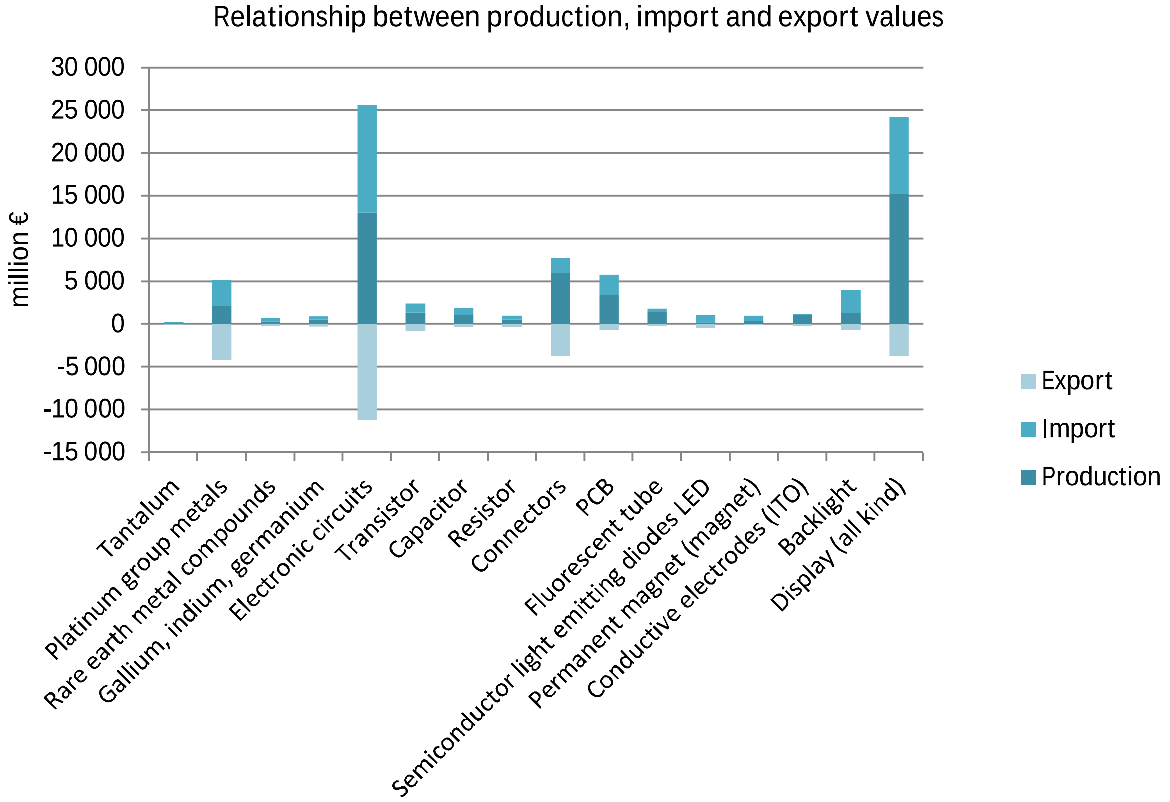


Figure 27: Relationship between production, import and export values for display, components and materials in Europe 2012. **Note**, the values for components and materials represents the whole industry, not the share which are used in displays

Figure 27 shows that the production of all kind of displays dominates the trade balance of the display group. In addition, large import values and low export values indicates high consumption of these articles in Europe either as components or end applications. As for components, backlights, permanent magnets and LEDs are mainly imported. For electronic circuits only around 40% of the whole trade comes from export indicating that a significant quantity of produced and imported electronic circuits are used as components in applications within Europe. A similar structure of the trade balance can be detected for PCB, connectors and conductive electrodes. Raw materials are mainly either produced or imported to Europe. As for exports, platinum group metals make an exception with a large export. However larger export value than production value in platinum group metals, indicated re-export of imported articles. Generally, a country is involved in re-exports if it has a major hub in a transport network that is used to redistribute goods to neighbouring countries. Re-exports can also stem from trading positions, for instance resulting from strategic stockpiling. As for gallium, indium and germanium material group larger production than import value supports the business analysis where production of these metals from secondary sources in Europe had been identified.

Criticality

Essentiality of the role of CRM

Indium-tin oxide is the primary material for LCD-based display applications and its specific properties make it essential for flat display production. It is an ideal material for the thin-layer electrodes due to its unique qualities, such as transparency, metal-like conductivity and heat-resistance (Buchert *et al.* 2012, Böni & Widmer 2011). Some substitution opportunities for ITO already exist (other TCOs, such as aluminium doped zinc oxide (AZO) and fluorine doped tin oxide (FTO)), but substitution of ITO in the flat display production is not currently possible without a loss of performance. The substitution of ITO with organic transparent conductors (PEDOT:PSS) in OLEDs may be possible in the future, and thus reduce indium dependence. (CRM_InnoNet 2013b.)

The distinctive phosphorescent and fluorescent properties of several CRMs, such as gallium, indium and rare earths are needed for producing backlighting for LCD displays. OLEDs and plasma technologies do not use backlighting but there are rare earths used in the displays themselves (Buchert *et al.* 2012).

<u>How will the vulnerability of the application evolve?</u>

The results of the great success story of the flat panel display industry can be seen everywhere in modern societies. Although new market areas may evolve in emerging countries, at some extent the market will quite certainly achieve saturation point and slower growth periods are probable. (DFF 2009.) Some drivers for enabling continued market growth include increased display size, price reductions, reduced display thickness, improvements in energy efficiency (legislative driver) and in colour quality, faster refresh times, 3D TVs (Weir *et al.* 2012) and other new developments. Large scale display production in Europe is in hands of non-European companies. There may be risk of the production moving out from Europe.

The scarcity of indium could become a bottleneck for LCD production, as substitution of ITO is not currently a viable option. The strong growth in ITO demand and the difficulties of expanding supply during recent years have affected to the price of indium (Böni & Widmer 2011). Since display markets still show continuous growth and new developments are entering the market, the demand for indium is likely to remain strong in the coming years. According to Böni & Widmer (2011) the flat panel display industries use more than 50% of primary, and up to 80% of all indium available. The indium supply from primary resources was around 670 tons in 2012 (Salazar & McNutt 2013); however more indium is produced secondarily from recycling. In 2011, global consumption of indium from primary and secondary sources was estimated to be over 1,800 tons (Salazar & McNutt 2012). Indium recovery has mostly been limited to pre-consumer recycling (European Commission 2010, Salazar & McNutt 2013). Due to the dissipative use of indium in flat display production process, only low ITO concentrations are presented in the actual products (EPOW 2011). However, a process for reclaiming indium directly from scrap LCD panels has developed. Earlier indium recovery from tailings was considered as insignificant, but recent process technology improvements have made recovery viable when the indium price is high. (Salazar & McNutt 2013.) Umicore in Belgium and Buss und Buss Spezialmetalle in Germany are European examples of indium secondary indium producers, but their feed consists mainly on manufacturing rejects. Also Sharp has developed a process for recovering indium from LCD displays (post-consumer), however it has not been commercialised.

For the LCD industry in particular, threats from competing technologies are not seen as very significant at present; CRT technology has already lost its share at the market, and plasma and OLED technologies are just emerging into the markets. However in the medium and long term these technologies may threaten the dominance of LCD (Frost & Sullivan 2013c). OLEDs are seen as a serious competitor for LCDs in time, but for now the higher price and shorter lifetime of OLEDs limits their deployment.

Available substitutes

Finding an economically profitable substitution for ITO would be a significant advantage in the markets due to the supply concerns and price fluctuations related to indium. As ITO is a critical component for flat panel display manufacturing, several research and development projects have been and still continue to be searching for a substitute for it (NanoMarkets 2012). There are some low cost commercial solutions (other transparent conductive oxides such as aluminium doped zinc oxide (AZO) and fluorine doped tin oxide (FTO)), but they suffer from lower performance compared to ITO. However, within the next 5 to 10 years many potential transparent conductive film technologies (such as ultrathin metal films and zinc oxide-metal-zinc oxide multilayers, carbon nanotubes and metal nanowire films, graphene films, organic transparent conductors (PEDOT:PSS), and printed metal grids) now under development are estimated to appear on the market. The only alternative ITO-free technology currently available is LED or so called “true-LED” display technology, mainly used nowadays in signage and billboards. However, true-LED technology uses indium-gallium-nitride-based diodes as the main active components in LED displays. In conclusion, ITO cannot yet be substituted in its main field of application, flat panel displays, either by an ITO alternative or a different display technology, without a loss of performance or the use of another indium containing component. (CRM_InnoNet 2013b.) The further development of such new technologies may reduce European dependence on indium. See CRM_InnoNet (2013b) report “Raw Material Profiles” for more information. Activities focused on substituting CRMs used in backlighting are discussed in the recent CRM_InnoNet report “Raw Material Profiles”, and also in section 4.2 “LED lighting”.

Environmental

Impact on European policies in case of supply disruption

The fast development of display technologies has enabled the creation of many new kinds of devices within the last two decades. One of the most important achievements in the field of display technology is the reduced energy consumption of new display types (Butter *et al.* 2011), as LCD monitors are much more energy efficient compared to previous CFT displays. However, LCDs are not able to compete with OLEDs, in which power consumption is approximately 80% lower. (Frost & Sullivan 2013c.) However, Butter *et al.* (2011) notes that it is also possible that new display types actually consume more energy due to their new functionalities. On the other hand, better displays can assist the development of paperless society and virtualization of products and activities. This path would lead to additional energy consumption by devices, but at the same time reduce the need of paper production and transports and have positive overall climate impacts. (Butter *et al.* 2011.)

In case of disruption in the LCD industry, the markets in Europe would probably move little by little towards newer technologies, such as OLEDs, and requisition of older technologies, such as CRT, is unlikely. As mentioned, OLED does not need backlighting as it generates its own light, and thus consumes less energy. This shift could lead to a high positive reduction of energy consumption and advancements towards present energy saving goals. Another environmentally friendly detail that favours OLEDs is that compared to other display technologies such as LCDs, they do not contain mercury. At the moment OLEDs still suffer from limited lifetime compared to LCDs, and this may weaken the energy efficiency of OLEDs, at least if the disruption situation occurs in short term, and the research focusing on increasing the lifetime has not yet proved to be profitable.

Innovation

Substitution activities already ongoing

There are several substitution activities already ongoing that aim to replace the current leader of the market, LCD displays. Although some of these technologies are already in use, their share in the market is still minor and R&D intensive, thus they are described as future technologies in this report. In smaller devices, such technologies are for example OLEDs, e-paper and AMOLEDs *(*active-matrix organic light-emitting diodes). Also some more radical innovations, such as touch sensitive 3Ds, very large area displays and reflective e-papers have arrived on the market. (Butter *et al.* 2011.) Other examples of two dimensional experimental or forthcoming technologies include surface-conduction electron-emitter displays (SEDs), laser TVs, carbon nanotubes and quantum dot displays. Also other 3D display technologies, holographic displays, cholesteric liquid crystal displays, polymer dispersed liquid crystals, blue phase liquid crystals, optically compensated bend LCDs and MEMs (microelectromechanical systems) based displays are also the subject of serious research efforts but are not expected to attain significant market shares over the next decade (Weir *et al.* 2012).

The market penetration of flexible, miniaturized, or holographic, and enhanced touch/motion feedback displays will generate new product concepts such as rollable e-books and e-papers, and also speed up the development and enhancement of existing concepts (for example integrated pico projectors) (Butter *et al.* 2011). OLED market penetration is expected to be around 30% in the TV and computer monitor sectors by 2020, and yet larger in portable PC and handhelds sectors (McKinsey & Company 2011). However, performance improvements in OLED technologies are essential to achieve competitive performance. Besides OLEDs, e-paper technologies (including electrophoretic, electrowetting, electrochromic and cholesteric liquid crystal) are seen as other promising competitors in the display market. (Weir *et al*. 2012.) The scale of the future market penetration of these new innovations is yet unclear, but it largely depends on the performance, lifetime and price factors of these devices.

4.4.3 Displays and screens – business summary

A summary of business analysis is presented in Table 19.

Table 19: A summary table of displays and screens application.

Dimension	Criterion	Required input
economic	Economic value of application or area	**The production in the EU of all different kind of displays, monitors and projection equipment was around €14 billion in year 2012 (Eurostat 2012). However, main production focused in Asia.**
	Position of EU in entire supply chain	**Display production of European companies focused on niche markets such as healthcare, security/defense, automotive and other non-consumer segments. However, several international companies have significant LCD TV and other display production/assembly in Europe.**
	Jobs involved in the EU	• **Manufacture of consumer electronics sector employed around 82,000 people in year 2010 (Eurostat 2010b).** • **Manufacture of other electrical equipment sector employed around 180,000 people in year 2010 (Eurostat 2010b).**
criticality	Essentiality of the role of CRM	• **ITO is essential for flat display production at the moment.** • **LCD display types need several CRMs for backlighting, OLEDs and plasma technologies do not use backlighting but there are rare earths used in the displays themselves (Buchert *et al.* 2012).**
	How will the vulnerability of the application evolve (as a result of RM and market developments)?	• **Flat display markets show continuous growth at present and new developments are emerging on the market. However, market saturation and slower growth periods are probable at some point. (DFF 2009.) Large scale production is in hands of non-European companies. There may be risk of the production moving out of Europe.** • **The scarcity of indium could become a bottleneck for LCD production, as substituting ITO is not yet an option. Indium recovery from pre-consumer wastes exists.**
	Available substitutes?	• **Indium substitution in flat panel displays is not possible without performance losses or the use of another In containing component. See CRM_InnoNet (2013b) report “Raw Material Profiles” for further information.** • **Substitution of CRMs used in backlighting: See section 4.2 “LED lighting” and CRM_InnoNet (2013b) report “Raw Material Profiles”.**
environmental	Impact on European policies in case of supply disruption	**In case of LCD supply disruption, faster transition to OLEDs may happen, and create energy savings (if current limitations in the use of OLEDs can be solved).**
innovation	Substitution activities already ongoing? What is the status of that research?	**Many new innovations and technologies in R&D stage on application level, or already penetrating to the market.**
	Principle of substitution: is substitution conceivable?	**OLED is considered to have the most potential, yet is still an emerging substitution technology.** The emissive electroluminescent layer in OLEDs is a film of organic compounds that emit light in response to an electric current. **The OLED market penetration is expected to be around 30% in the TV and computer monitor sectors by 2020 (McKinsey & Company 2011). Performance improvements are essential for achieving a competitive market position (Weir *et al.* 2012).**
	Opportunity for Europe	**In Europe there is R&D on display technology and therefore the development of new less CRM dependent technologies may create possibilities in the future markets for European companies.**

4.5 Large household appliances (Washing machine)

4.5.1 Large household appliance technologies and CRM dependence

Large household or major appliances are usually defined as large machines accomplishing some routine housekeeping tasks. The appliances can be roughly divided to four groups: refrigeration equipment (including freezers and refrigerators), stoves (including cookers, ovens, hobs, hoods and microwaves), washing equipment (including washing machines, dryers and dishwashers) and miscellaneous such as air conditioners. Some of these appliances contain components that may include CRM. As for stove group's application direct link to CRM can't be detected and therefore these will be beyond our scope. Table 20 presents the link between CRM and large household appliances.

Table 20: Large household appliances and their link to CRM.

Large household appliance	CRM dependent component	CRM used in component
Refrigeration equipment (including also freezers)	Compressor	Nd, Dy
Washing equipment (including dryers)	Electric motor Electronics	Nd, Dy Pd, Ta, Ru, Ga, Ge, In, Sb
Dishwashers	Electric motor Electronics	Nd, Dy Pd, Ta, Ru, Ga, Ge, In, Sb
Air conditioners	Compressor Electronics	Nd, Dy Pd, Ta, Ru, Ga, Ge, In, Sb

Table 20 shows that in most cases CRM can be found in electric motors and in compressors which include an electric motor. In addition, electronics (PCBs) are mounted in modern devices. Due to the similarities between these appliances only one application will be studied as an example. Therefore this section will focus on washing machine, and includes dryers as a result of to the screening in section 3.

The primary purpose of washing machines is to wash clothes, household linen and personal items. There are two basic designs on the market: drum type machines (horizontal axis) and “other” types (generally classified as vertical axis but with a wide range of technologies imparting mechanical action onto the clothes load). Vertical axis machines include traditional technologies such as agitators and impeller types, but also a range of new technologies such as turbo jet and nutator types. In addition, two types of control systems exist: automatic clothes washing machines and manual or semi-automatic clothes washing machines where the user must intervene at one or more stages during the cycle. (Waide *et al.* 2011.)

The structural composition of washing machine is presented in Table 21.

Table 21: A structural composition of washing machine application.

Washing machine	CRM content	Comments
The Frame		
Electric motor		
Permanent magnet		
Iron boron magnets		Not all motors use NdFeB magnets
NdFeB	Nd, Dy, Pr, Tb	NdFeB magnet contains also small ammount of Dy, Pr and Tb
Electronics		
Printed circuit board		
Plating	Pd	Not very common to use Pd as plating, generally Ni/Cu an Au are used
Components		
Capacitors	Ta, Pd, Nd	
Resistors	Ta, Ru	
Semiconductors	Ga, Ge, In, Sb	
Transistors	Ga, Ge	
Electronic and integrated circuits		
Capacitors	Ta, Pd, Nd	
Resistors	Ta, Ru	
Semiconductors	Ga, Ge, In, Sb	
Transistors	Ga, Ge	
Connectors	Pd, Ru, Be	
Cables		

The washing machine consists of a frame which is usually manufactured of steel. Within the frame an electric motor is placed in order to rotate the drum. These motors include permanent magnets of which some are neodymium magnets. Kozawa (2011) has reported that neodymium magnets are used in washing machine motors to increase performance by increasing spin-dry power and reducing motor noise.

In Japan the share of imported washing machines including permanent magnets has been studied. In Figure 28 the share of washing machines shipped to Japan that includes permanent magnets is presented. (Sekine 2013.)

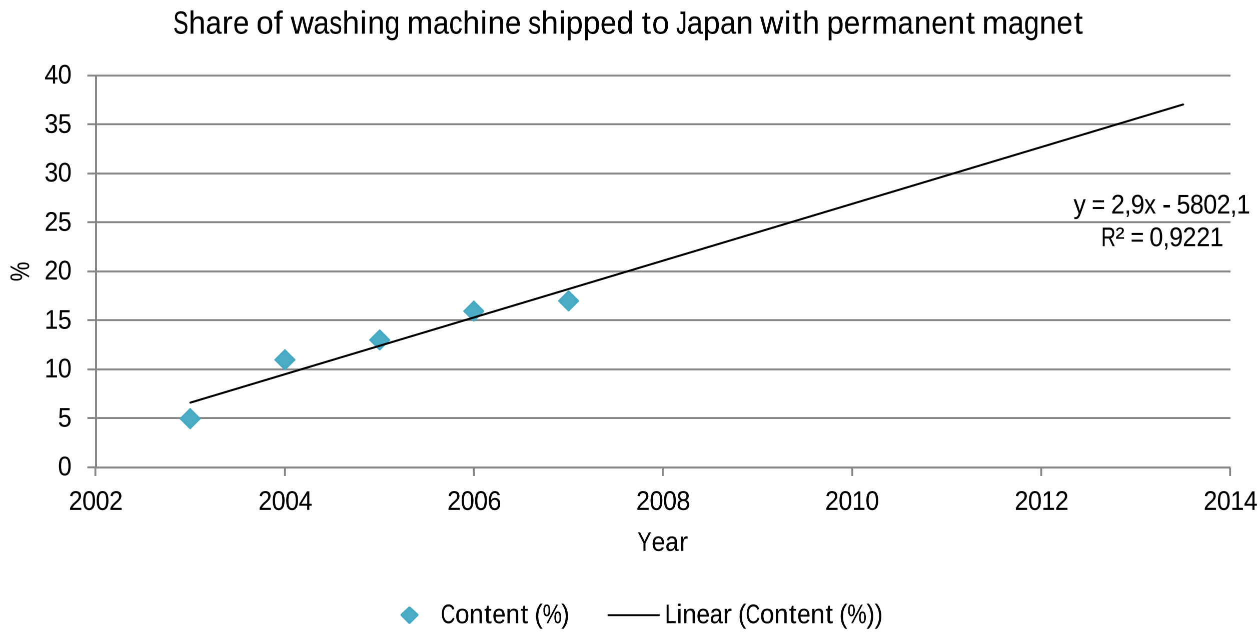


Figure 28: Share of washing machines imported to Japan including permanent magnets (Sekine 2013, modified).

In Figure 28 a linear fitting has been carried out on the data in order to roughly estimate the potential share of washing machines including permanent magnets today. In addition, Sekine (2013) stated that one washing machine contains between 100 and 200 grams of permanent magnets with Nd and Dy concentrations of 28% and 3% respectively (Sekine 2013). As a result we can estimate that between 25% and 30% of today's washing machines imported to Japan contains permanent magnets. Assuming the ratio is the same in the washing machines produced in Europe, estimations on permanent magnet and rare earth metal amounts can be calculated (Table 22).

Table 22: Estimation on washing machines produced in Europe containing permanent magnets (Sekine 2013, Eurostat 2012, modified).

Scenario	Share of washing machines with PM	Amount of washing machines with PM (20,371,615 units EU production in 2012)	PM amount		Nd amount (28% in PM)		Dy amount (3% in PM)	
			100 g/item (t)	200 g/item (t)	100 g/item (t)	200 g/item (t)	100 g/item (t)	200 g/item (t)
1	25%	5,097,144	510	1,020	143	285	15	30
2	30%	6,116,572	612	1,224	171	342	18	36

Table 22 shows that the total amount of permanent magnets in European washing machines can be estimated to be between 500 to 1,200 tons. In addition, Nd and Dy amounts are estimated to be between 143 to 342 and 15 to 36 tons respectively. Comparing these metal amounts (washing machines in Europe) to the total (global) permanent magnet metal consumptions (16,700 tons of Nd and 480 tons of Dy) (Peiro *et al.* 2013a), the share of Nd consumption would vary from 1% to 2% while for Dy the share would vary from 3% to 7.5%.

A more detailed description of permanent magnets is described in section 4.1 within the MRI application. In addition, electronics are integral to modern washing machines. Basic electronic components such as capacitors and resistors may contain CRM. A wider description of electronic components and their CRM can be found in section 4.6.

4.5.2 Analysis of CRM-related washing machine market and supply chain

Economics

The global demand for major household appliances (white goods) in 2013 has been estimated to be approximately 497 million units. The demand has been forecasted to rise 2.8% annually approaching 500 million units by 2013. The demand mainly arises from the Asia/Pacific region with a 36% share after which North America and Western Europe followed with shares of 23% and 21% respectively. Future demand growth will be driven by market penetration in developing countries. In developed regions the sales will depend mainly on replacement demand such as new features driving upgrading. Washing machines will contribute to the overall growth in demand for major household appliances; respectable growth has been forecasted. (Freedonia 2009.)

Stöckle (2013) has estimated the world market for large household appliances (washing machines, tumble dryers, dishwashers, refrigerators, freezers, cookers/ovens, hobs, hoods, microwave ovens) to be approximately $176 billion (around €130 billion) in 2012. The growth for the year 2013 has been forecasted to be around 4%. As for washing machines, the European sales were approximately 15.6 million units in 2012, 2.1% less than in 2011. (Stöckle 2013.) In Table 23 the sales of various domestic appliances both in Western and Eastern Europe is presented including estimated unit price.

Table 23: The sales (units and value) between 2006 and 2009 for washing machines, dishwashers, cooling appliances and freezers (Stöckle 2010, modified).

	2006		2007		2008		2009		Sum (computational)	
	Units million	Value b€	Units million	Value b€	Units million	Value b€	Units million	Value b€	Units million	Value b€
Western Europe 13 countries	40.2	19.2	40.3	19.4	39.6	18.7	38.5	18.0	158.6	73.3
Eastern Europe 5 countries	5.9	1.9	6.7	2.2	7.0	2.4	6.1	1.8	27.7	8.3
Sum	46.1	21.1	47.0	21.6	46.6	21.1	44.6	19.8	184.3	83.6
Unit price (€/unit)*	457.7		459.6		452.8		444.0		453.6	

*Unit price has been calculated based on the sold unit quantities and their values.

Table 23 shows that both the amount and value of washing machines, dishwashers, cooling appliances and freezers sales in Europe generally decreased between 2006 and 2009. The combined (both Western and Eastern Europe) sales in 2009 were approximately 44.6 million units which correspond to €19.8 billion.

In addition, Stöckle (2013) has reported that the unit sales for the same application group in 2011 and 2012 were 42.0 and 41.1 million units respectively and the share of washing machines from this application group would be approximately 38%. This would result to approximately 15.5 million washing machines sold in 2012. (Stöckle 2013.) Since these figures represent the quantity of 23 European countries, we cannot directly compare with the figures presented in Table 22. However, 13 Western European countries present around 85% and 90% of the total (13 Western countries + 5 Eastern countries) unit sales and value respectively in Table 23. Therefore, together with the five Eastern European countries the unit price could also be used as a rough estimate for the 23 European countries. As a result the sales value for the years 2011 and 2012 would be around €19 and €18.5 billion respectively. In addition, applying the 38% washing machine share from the total application group, the washing machine sales in Europe (23 countries) would be in magnitude of €7 billion in 2011 and in 2012.

Based on the data from Eurostat's centralized PRODCOM data base the production in EU as a value for cloth washing and drying machine group was approximately €4.6 billion in 2012. In addition, import to EU and export from EU for the same product group was approximately €1.0 and €0.9 billion respectively. (Eurostat 2012.)

Position of Europe in the supply chain and main actors

The supply chain of a washing machine is rather straightforward consisting of seven steps. In Figure 29 the supply chain of washing machine is presented. The supply chain is focused on the permanent magnet branch while other components such as electronics are presented later in Figure 31.

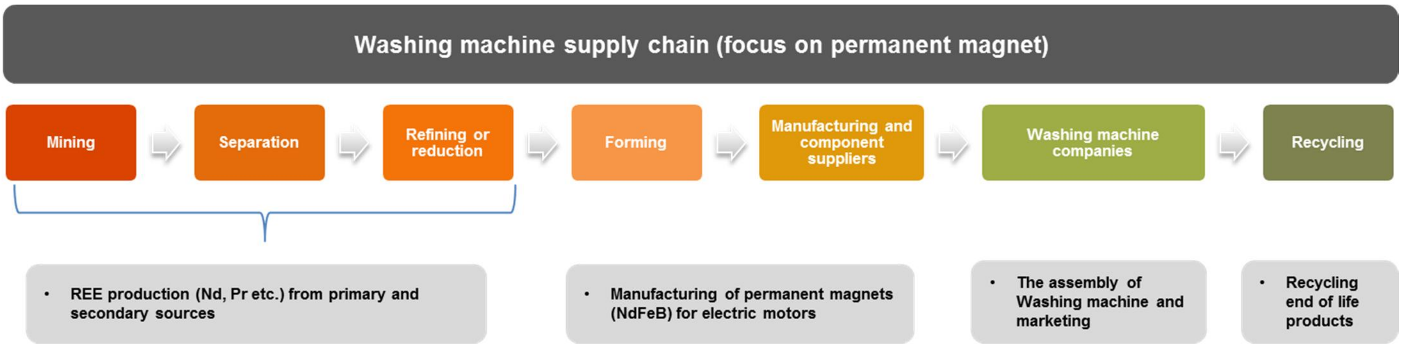


Figure 29: The supply chain of washing machine (focus on permanent magnet).

The supply chain can be roughly divided to four different stages. The first stage is raw material production from primary or secondary sources. The material can be in form of pure metal powder or alloy. The second stage is the manufacturing of permanent magnets. At this stage the component manufacturers produce magnets for different target applications, including wind turbines, electric motors and MRI machines. Quality and characteristic requirements for the magnet vary based on the target application. The third stage of the supply chain is the assembly of the components to produce a comprehensive washing machine which can be marketed and sold. The final stage of the supply chain is the recycling end of life products.

Permanent magnet manufacturing is concentrated in Asia. More detailed description of permanent magnet producers is described in section 4.1.

China is the leading manufacturer in the refrigerator, washing machine and microwave oven segments exporting such products to the US, Western Europe and throughout Asia. Though overall manufacturing is expected to increasingly shift towards Asia, Western Europe and the US will remain major manufacturer due to their technical competence. (Freedonia 2009.)

Bonaglia (2007) classified home appliance producers into five categories depending on their market position (Table 24). None of the manufacturers commanded more than 10% of the world market, however on regional levels high market concentrations are observed. For example the top five actors covered nearly 99% and 60% of the total markets in US and Europe respectively. Only a few of the world's top ten manufacturers were present in all key markets. Others had a strong regional position or were leaders in specific niche area (often high quality). (Bonaglia 2007.)

Table 24: The orientation of major home appliance manufacturers (Bonaglia 2007, modified).

Orientation	Company
Global players	Whirlpool (US)
	AB Electrolux (Sweden)
	General Electrics (US)
Global aspirants	Bosch-Siemens (Germany)
	Haier (China)
	LG Electronics (Korea)
Strong regional players	Matsushita Panasonic (Japan) in Asia
	Sharp (Japan) in Asia
	Toshiba (Japan) in Asia
	Hitachi (Japan) in Asia
	Samsung Electronics (Korea) in Asia
	Daewoo Electronics (Korea) in Asia
	Maytag (US) in North America
	Miele (Germany) in Western Europe
	Candy (Italy) in Western Europe
	Indesit (Italy) in Western Europe
Strong local players with some regional presence	Arçelik (Turkey)
	Mabe (Mexico)
	Multibras (Brazil)
	Fisher & Paykel (New Zeland)
Domestic and niche players	Sub Zero/Wolf (US)
	Guangdong Midea Group (China)

In addition, the largest companies on major appliance segment in 2010 have been presented in Table 25.

Table 25: Top five major appliance manufacturers (Euromonitor 2010, modified).

Company	Global ranking 2010	% Unit volume share 2010	% Unit volume growth 2009-2010
Whirlpool Corp	1	10.5	4.4
Electrolux AB	2	7.3	3.0
Haier Group	3	6.9	13.1
Bosch & Siemens Hausgeräte GmbH	4	5.8	5.4
LG Corp	5	5.1	5.4

The Table 25 shows that all five largest actors in major appliance segment constitute approximately 35% of the total market and only Whirlpool achieving over 10% market share. Especially Chinese Haier Group had significant growth between 2009 and 2010, while the other actors have settled to more modest growth.

A summary of main actors in the supply chain of washing machine is presented in Figure 30.

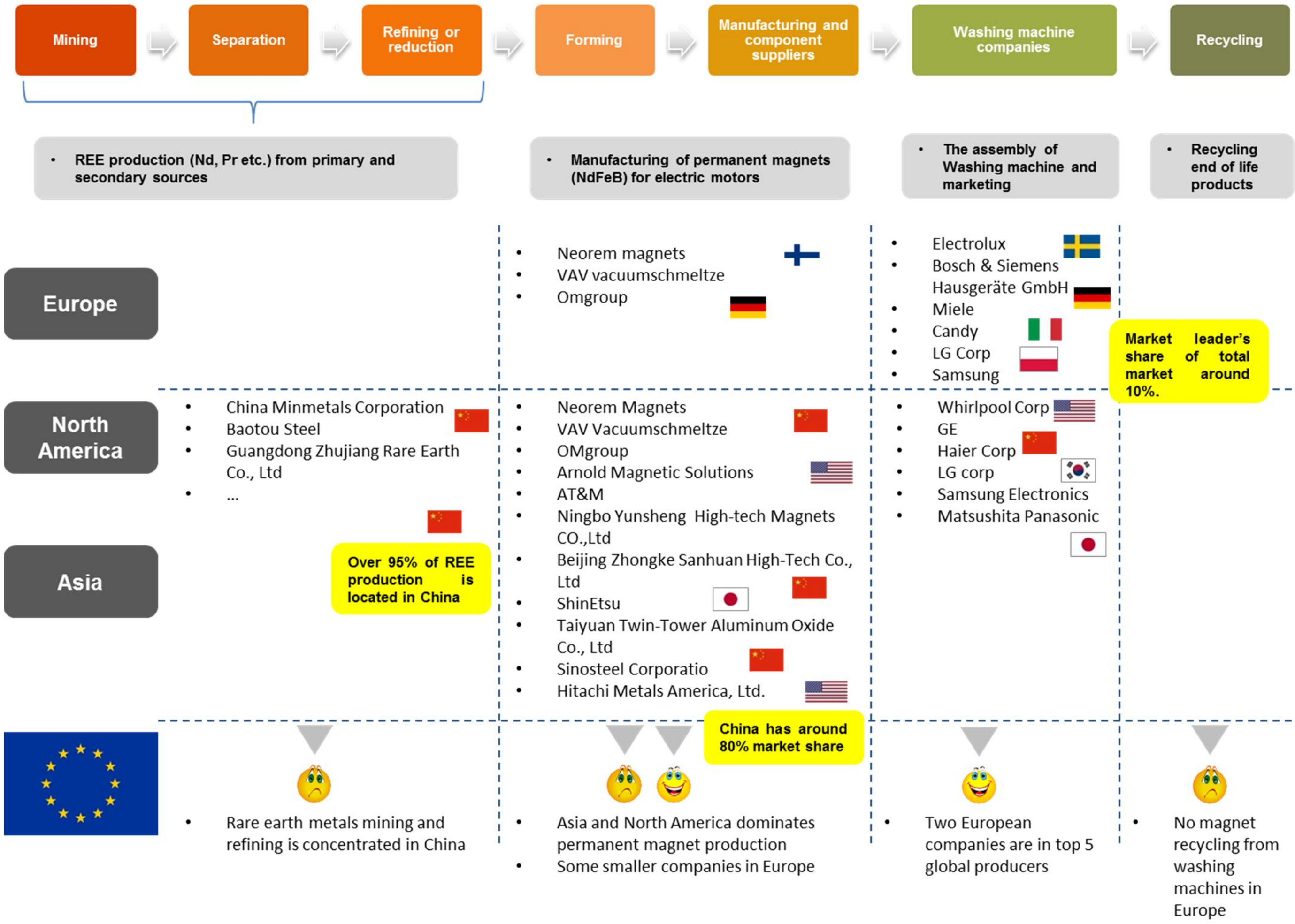


Figure 30: Main actors in the supply chain of washing machine (focus on permanent magnet).

Jobs involved in EU

Based on Eurostat's structural business statistics, the manufacture of electric domestic appliances sector, which includes washing machine production, employed 195,000 people in 2010 within the EU. The largest employing country was Germany (45,000 jobs). The next largest employing countries were Italy and Poland (40,000 and 27,000 jobs respectively). (Eurostat 2010b.) However, direct employment in washing machine production is less than reported above since data provided by Eurostat concerns the whole sector.

EUROSTAT data interpretation

The quantitative supply chain analysis was carried out on data from Europe's PRODCOM database. More detailed information on the data and application composition can be found in Appendix 6 (Washing machine). The data from PRODCOM has been applied to produce supply chain illustration for production with largest producing countries in EU (Figure 31). **However, it is essential to understand that the shares/dimensions of different industries (box sizes) represent the production for the whole industry not only the share which is used in washing machine production.**

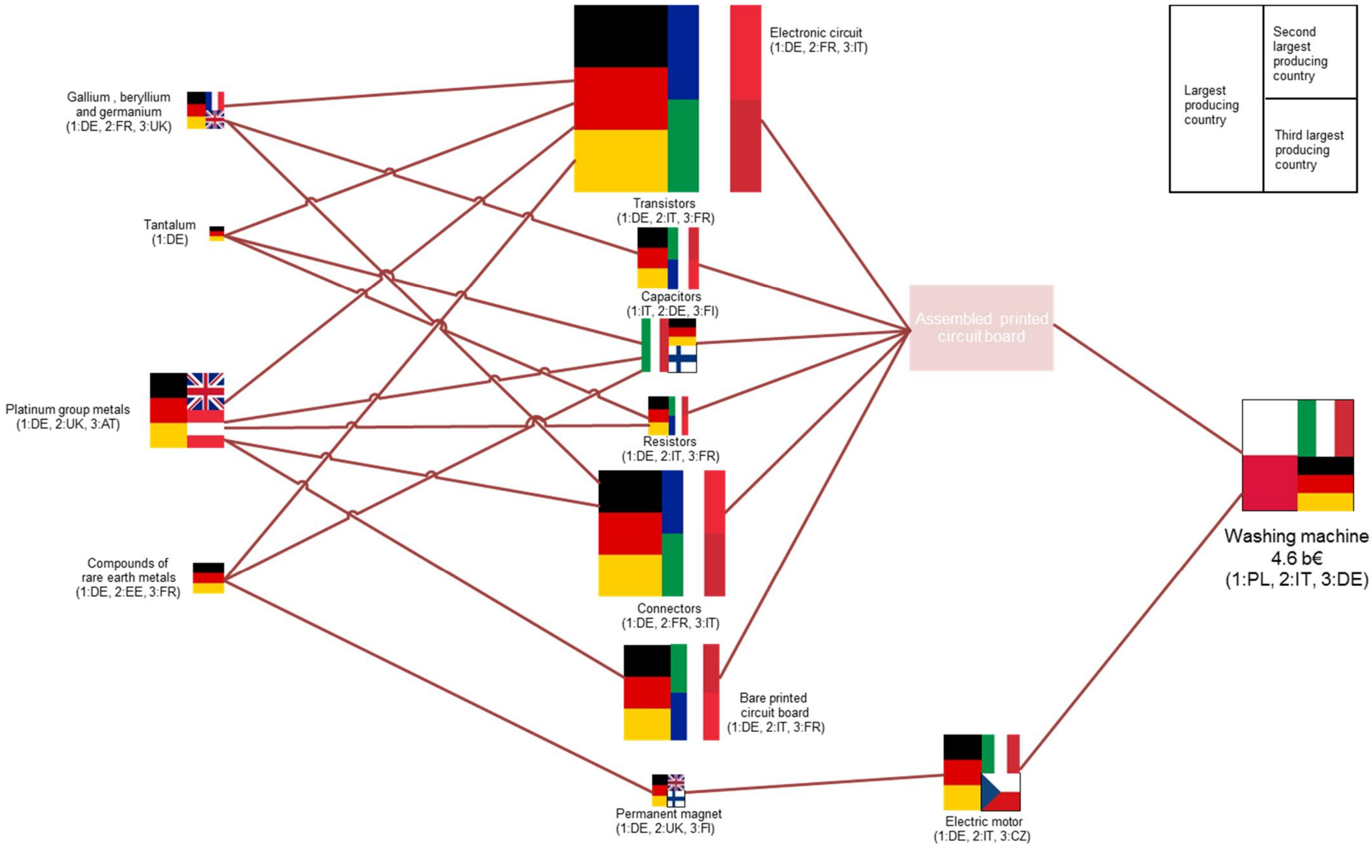


Figure 31: EU production of washing machines including dryiers and related (sub)-components and materials. (Sub)-components in pink boxes have no corresponding PRODCOM group and therefore no statistically defined value and are included for completeness. Each box presents total production value, not the value of components/materials which are used only in washing machine applications. In addition, the largest EU producing countries are presented.

The structure of the washing machine supply chain resembles the MRI supply chain (Figure 31). The production in terms of value exists both on component and end application level. However, a trend of production increasing towards the end application can be noticed, especially on the electric motor branch. An exception in the material production is platinum group metals which production in Europe is significantly larger than other material production.

Washing machine production is concentrated in central Europe, with Germany as the main producer country at nearly every stage. Other large producer countries are Italy and France. Poland has the largest white goods production in Europe. According to Euromonitor (2011) companies like Bosch & Siemens Hausgeräte and Electrolux have in the past two years moved their production from Western European countries such as Germany and Italy to Poland due to the cheaper labour and geographical location. In addition, LG and Samsung have invested in Poland and are aiming to transfer entire production in Europe to Poland. (Euromonitor 2011.) The UK has platinum group metals production with companies such as Johnson Matthey Ltd.

The relationship between production, import and export value for all components, materials and the end application is presented in Figure 32. Note the values for components and materials represent the entire industry, not just the share used in washing machine.

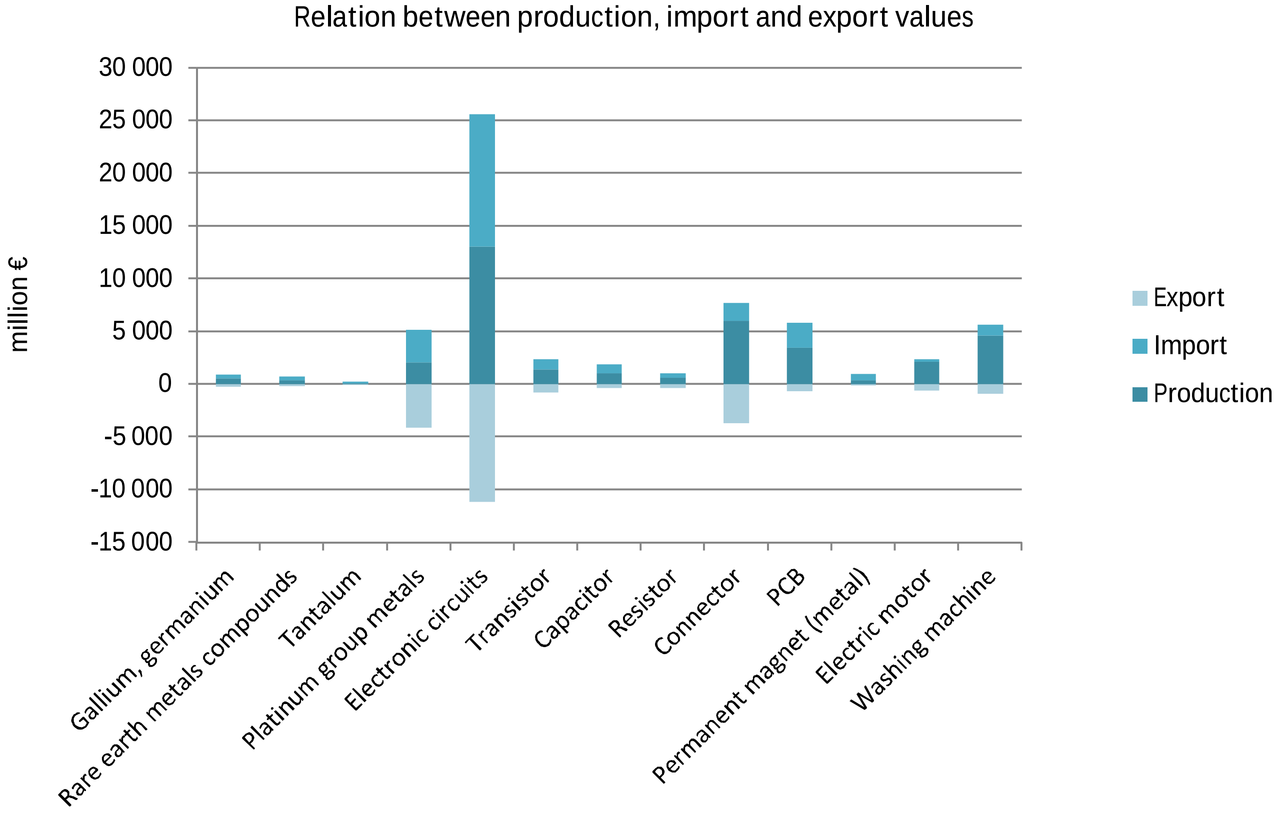


Figure 32: Relationship between production, import and export values for Washing machine application, components and materials in Europe 2012. **Note** the values for components and materials represent the whole industry, not the share which is only used in washing machines.

In Figure 32 it has been assumed that production plus import which are on the positive side of x-axis present the cumulative value of articles which are within Europe. Consequently, the value of export is on the negative side expressing the value which leaves Europe.

Figure 32 shows that the production of washing machines dominates its trade balance. In addition, low import and export values indicate high consumption of European products in Europe. Potential reasons for this could be transport costs, brand loyalty as well as the presence of widely different standards. For electronic circuits only around 40% of the whole trade comes from export indicating that a significant quantity of produced and imported electronic circuits are used as components in applications within Europe. A similar structure of the trade balance can be detected for PCB. An even larger share of production in the trade balance of electric motor also indicates the use as a component in applications produced with in Europe. Raw materials are mainly either produced or imported to Europe. As for exports, platinum group metals make an exception with a large export. However larger export value than production value in platinum group metals, indicates re-export of imported articles. Generally, a country is involved in re-exports if it has a major hub in a transport network that is used to redistribute goods to neighbouring countries. Re-exports can also stem from trading positions, for instance resulting from strategic stockpiling.

Criticality

Essentiality of the role of CRM

NdFeB magnets are used in small motors to reduce the size of the motor and noise. In washing machine motors, the use of NdFeB magnets has increased spin-dry power and decreased noise. (Kozawa 2010.) However, most of motors used in washing machines are common AC motors or universal AC-DC motors which use ferrite magnets.

How will the vulnerability of the application evolve?

The pressure to reduce energy consumption and increase the use of energy efficient equipment will increase in the future. Since NdFeB magnet motors are more energy efficient than conventional AC motors, it can be assumed that NdFeB magnet motors will be become more common in large household appliances in the future. For example in Japan, air conditioners used AC induction motors in the 1980s. However, due to the reinforced energy conservation act in 1999 and the introduction of fuel efficiency standards under the act in 2003 as well as development of brushless DC motor in 1990s, the air conditioner manufacturers started to improve the efficiency of their products. Nearly all domestic air conditioning manufacturers adopted NdFeB magnets in or after 2003 which have reduced the energy consumption of their products. Compared with normal motors, the motors using NdFeB magnets have been reported to improve the low-speed motor efficiency by approximately 30%. (Kozawa 2010.) Based on the information from Sekine (2013) a similar type of development is taking place to some extent for other domestic appliances such as washing machines.

Environmental

Impact on European policies in case of disruption

Substituting common AC motors with new motors using NdFeB magnets would increase the energy efficiency of the application and consequently decrease CO_2 emissions. Hitachi has estimated that a 1% improvement in the efficiency of electric motors would save power equivalent to the output of a 500 MW thermal power station (Hitachi 2013).

Innovation

Substitution activities already ongoing

Manufacturers have invested heavily to improve the performance of washing machines. Presutto (2007) reported that further improvement is unlikely unless a step change in the product or the washing process can be devised. However, it is unlikely that these technologies will come to market for some years. The two research areas are:

- Washing with steam
- Washing with air and negative ions. (Presutto 2007.)

Researchers at the University of Leeds, UK, have developed a new way of cleaning clothes using less than 2% of the water and energy of a conventional washing machine. The process is based on the use of plastic granules (or chips), which are tumbled with the clothes to remove stains. A range of tests, carried out according to worldwide industry protocols to prove the technology performs to the high standards expected in the cleaning industry, show the process can remove virtually all types of everyday stains as effectively as existing processes whilst leaving clothes as fresh as normal washing. In addition, the clothes emerge from the process almost dry, reducing the need for tumble-dryers. (Uni. Leeds 2008.)

Defra reported potential novel clothes washing technologies:

- Polymer pellets (Xeros washing system)
- Steam
- Ultra sound
- Ozone
- Silver ions. (Defra 2009.)

4.5.3 Washing machine – business summary

A summary of business analysis is presented in Table 26.

Table 26: A summary of washing machine application.

Dimension	Criterion	Required input
economic	Economic value of application or area	**The production value in Europe for cloth washing and drying machine group was approximately €4.6 billion in 2012 (Eurostat 2012).**
	Position of EU in entire supply chain	**Europe has end production in domestic appliances while the production of permanent magnets is outside Europe.**
	Jobs involved in the EU	**195,000 persons employed in 2010 in manufacture of electric domestic appliances sector (Eurostat 2010b).**
criticality	Essentiality of the role of CRM	**NdFeB magnets are used only in some washing machine's electric motors. Therefore, rare earths are not directly essential to all washing machines.**
	How will the vulnerability of the application evolve (as a result of RM and market developments)?	**The pressure to reduce energy consumption and increase the use of energy saving equipment will increase in future in order to cut CO_2 emissions. This might lead to the use of more NdFeB magnet motors for their better energy efficiency.**
	Available substitutes?	**See section 4.1.3 for NdFeB magnets in MRI.**
environ mental	Impact on European policies in case of supply disruption	**Replacing conventional AC motors with NdFeB motors would decrease energy consumption and therefore reducing CO_2 emissions.**
Innovation	Substitution activities already ongoing? What is the status of that research?	**Xeros has developed with the University of Leeds a washing technology which utilizes polymer pellets and consumes 2% of the water and energy of a conventional washing machine. However a motor is needed to rotate the drum.**
	Principle of substitution: is substitution conceivable?	**The Xeros machine entered to the market in 2010.**
	Opportunity for Europe	**The development of new washing techniques or electronic motors which are not as dependent on CRM. In addition, greener solutions in the products compose possibilities.**

4.6 Assembled printed circuit boards

4.6.1 Assembled printed circuit board technologies and CRM dependence

Every electronic product contains at least one printed circuit board (PCB). A printed circuit board consists of electronic components, such as microprocessors, resistors, capacitors, sensors and magnets. The components are connected together with embedded copper wire (EPOW 2011.) to form a working circuit or assembly. The actual board is most commonly made of plastic or glass-fibre and resin composites. According to EPOW (2011) most of the electronic components attached to printed circuit boards contain at least one CRM. The precise composition of PCBs in different kind of devices is not widely available, and this section presents only some general information on critical materials commonly used in printed circuit boards.

Printed circuit boards are not classified according to the application in which they are used. Their distribution depends on the structural and material composition requirements, which leads to the situation that there may well be similar kinds of PCBs in use in varying applications, such as computers or wind turbines. The structure of a PCB is determined by the requirements of electronics used. The most important distribution is between one and multi-layer PCBs, which is defined by the component density requirements. PCBs can also be distributed according to the board material used; for example FR-4 (glass epoxy), or special laminates for more demanding applications (high temperature, frequency etc.) are in use. In conclusion, every device needs its own kind of PCBs and the structure of it depends on the functional requirements of application. (Ylilammi 2013.)

Table 27: A structural composition of a printed circuit board.

Printed circuit board (with components)	CRM content	Comments
Printed circuit board (bare without components)		
Plating	Pd	Not very common to use Pd as plating, generally Ni/Cu and Au are used
Components		
Capacitors	Ta, Pd, Nb	
Resistors	Ru, Ta	
Semiconductors	Ga, Ge, In, Sb, Ta	
Transistors	Ga, Ge	
Electronic and integrated circuits		
Capacitors	Ta, Pd, Nb	
Reistors	Ta, Ru	
Semiconductors	Ga, Ge, In, Sb, Ta	
Transistors	Ga, Ge	
Connectors	Pd, Ru, Be	

CRMs used in PCBs include:

- Antimony (Sb): Antimony is used as a dopant in n-type silicon semiconductors, amounts used are very small (EPOW 2011). Also used as a flame retardant in PCBs.
- Beryllium (Be): High performance electrical connectors use beryllium copper alloys as contacts (EPOW 2011). Beryllium is used as an alloy with copper for contacts because it is six times stronger than copper alone (Ylilammi 2013). Alloys contain around 2%, and an average PC contains approximately 2.1 grams of Be. Beryllium oxide is most commonly used as an electronic substrate. High power devices and high-density electronic circuits for high speed computers use beryllium

oxide. (EPOW 2011.) Beryllium oxide ceramic has an exceptionally high thermal conductivity and therefore it is used as an insulator plate between the silicon chip and the metallic package in high-power devices. Previously, BeO powder slurry in oil was used to fill power transistor packages for the same reason. Nowadays this is rare because of the high toxicity of Be. Beryllium is also a p-type dopant in III-V compounds like GaAs, AlGaAs, InGaAs and InAlAs. (Ylilammi 2013.)

- Gallium (Ga): Ga containing III-V semiconductors GaAs, AlGaAs, InGaAs etc. are used in high-frequency transistors, light emitting diodes and solar panels (Ylilammi 2013). Gallium arsenide (GaAs) is used in the circuitry of wireless and wi-fi products (EPOW 2011). The majority of gallium consumed is used in integrated circuits (Salazar & McNutt 2013). In 2010, 106 tons of gallium was used in PCBs (Peiró *et al.* 2013).

- Germanium (Ge): Ge was extensively used in making the first generation transistors but nowadays this use is very small but still exists. An alloy of silicon and germanium (SiGe) is used in high-frequency diodes and transistors and also in power semiconductor devices. Ge is also used as a substrate material for III-V semiconductors for solar cells and light emitting diodes. (Ylilammi 2013.) It can be used as an alternative to GaAs semiconductors (EPOW 2011). Approximately 9 tons of Ge was used in PCBs in 2010. (Peiró *et al.* 2013.)

- Indium (In): According to Ylilammi (2013) indium can be used as p-type dopant in silicon but is seldom used because B, Al, Ga can be used instead. Indium antimonide (InSb), indium phosphide (InP) and indium nitride (InN) are semiconductors used in infrared light detection, magnetic field sensors, fast transistors, light-emitting diodes and solar cells. Indium is used in III-V semiconductors such as InGaAs etc. for fast transistors and light emitting devices. Indium is used in several solder formulations, for example $In_{90}Ag_{10}$ can solder silver, fired glass, and ceramics. Indium is also used as a thermal interface material in the form of pre-shaped foil sheets fitted between the heat-transfer surface of a microprocessor and its heat sink. (Ylilammi 2013.) Around 6 tons of In was used in minor alloys in 2010. (Peiró *et al.* 2013.)

- Niobium (Nb): Niobium is used in ceramic capacitors.

- Palladium (Pd): Palladium or palladium alloys are used as an electrode metal in multilayer ceramic capacitors (Ylilammi 2013), conductive tracks in hybrid integrated circuits and plating connectors and lead frames (CRM_InnoNet 2013b). It is a key material of multi-layer ceramic capacitors, a passive component used in consumer electronics devices such as computers. Annual demand for palladium producing these capacitors is over 15.5 tons (EPOW 2011). Pd is also used as a plating material in electronic components to improve adhesion of solders and to prevent oxidation in connectors (Ylilammi 2013).

- Ruthenium (Ru): Ru is used in thick film chip resistors. The amount used is around 12.2 tons annually representing around 61% of the total supply of Ru. (EPOW 2011.) Ruthenium alloys are used in electrical contacts because of their good wear resistance. Metallically conducting ruthenium oxide can be used to replace platinum metal electrode in certain microelectronic devices. (Ylilammi 2013.)

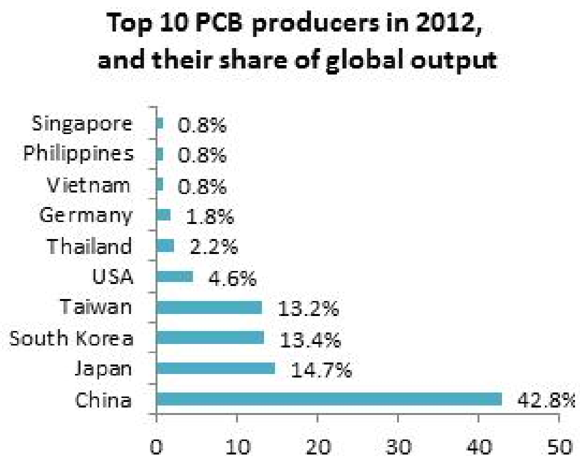
- Tantalum (Ta): Tantalum is used as an anode metal in tantalum electrolyte capacitors where the electrolyte forms a thin layer of insulating tantalum pentoxide which gives a very high capacitance density (Ylilammi 2013). More than 60% of tantalum is used in capacitors (Salazar & McNutt 2013), however, only 3-5% of all capacitors use Ta. It is also used in semiconductors (EPOW 2011) and resistors. Mixtures containing tantalum oxide are used in gate dielectrics of very small MOS (metal-oxide-semiconductor) transistors and as dielectrics of other capacitors in integrated circuits. Tantalum nitride (TaN) is used as a diffusion barrier beneath copper metal. (Ylilammi 2013.)

4.6.2 Analysis of CRM-related assembled printed circuit board market and supply chain

Economics

<u>Global PCB market</u>

The market for PCBs is growing fast. The world's total estimated production value of PCBs was $58.9 billion (around €42.9 billion) in 2011 (WECC 2012). The market grew 1.7% in 2012, and reached nearly $60 billion (around €43.6 billion). Figure 33 represents the ten biggest PCB producing countries and world output by region in 2012. Asia's share of the world PCB production is currently over 90%. China is the most important Asian producer with a share of almost 43% of global output. Germany is the biggest European producer of PCBs with a 1.8% share of global output, when Europe's total share of PBC production accounted for 4.5%. (IPC 2013.)



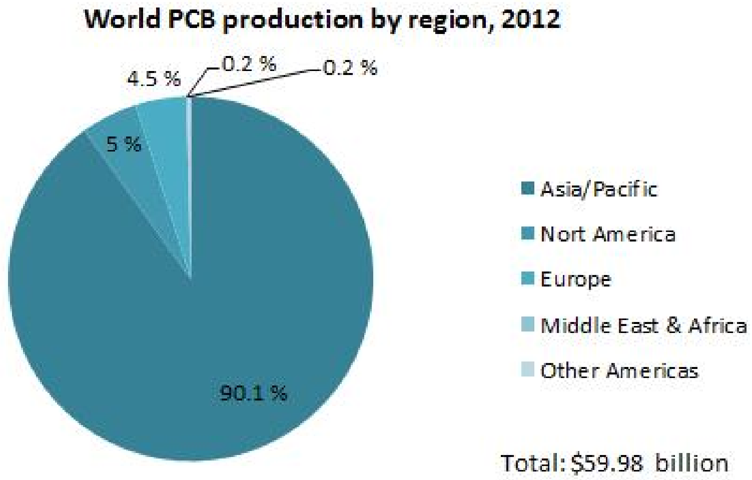


Figure 33: Top 10 PCB producers in 2012 and their percent of global output (based on value of production), and the global production by region (IPC 2013, modified).

The total market volume for European passive components that does not store energy in themselves (i.a. capasitors, resistors) in 2012 was approximately €4.20 billion (€4.17 billion in 2010) containing the capacitor market of €724 million (€713 million in 2010) and resistor market of €1.62 billion (€1.61 billion in 2010) (EECA-EPCIA 2012). The overall market value for active components in Europe in 2010 was around $22.8 billion (€17.0 billion), consisting of the market for integrated circuits which reached at $6.80 billion (approximately €5.07 billion) (BCC Research 2012b).

Position of EU in supply chain and main actors

Rapid technological changes are driving the global PCB markets. The market is highly cyclical, competitive and fragmented in nature. In 2012, around 2,800 competitors operated in the global market, the largest manufacturer having a market share of only around 4%. The top 20 manufacturers accounted for a share of 43% of output. (AT&S 2013) Western European end markets for printed circuit boards are shown in Figure 34.

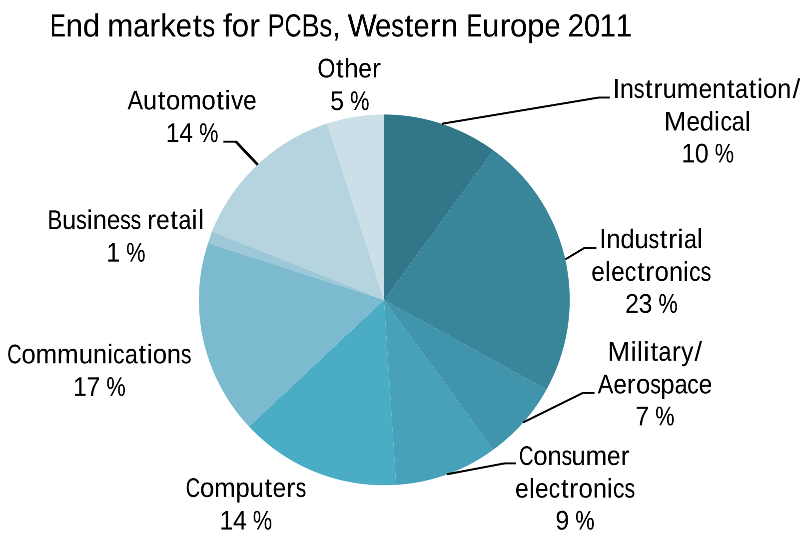


Figure 34: End markets for PCBs in Western Europe, 2011 (WECC 2012, modified).

AT&S Austria Technologie & Systemtechnik AG (AT&S) is the major producer of PCBs in Europe and India, and it also has a position among the industry leaders worldwide in innovation and development of PCB manufacturing technologies. AT&S have manufacturing plants in Austria, India, China and Korea. Austrian, Indian and Korean production facilities are specialized on smaller deliveries for the automotive and industrial sector, while the facility in China produces large batches for mobile device customers. (AT&S 2011.) Other important European manufacturers and component suppliers include STMicroelectronics, ASML, NXP, Epcos, Wima, TT-Welwyn and Infineon Technologies.

In Figure 35 the supply chain of assembled PCB is presented. The chain has focused on component production and does not comment on the applications that consume these.

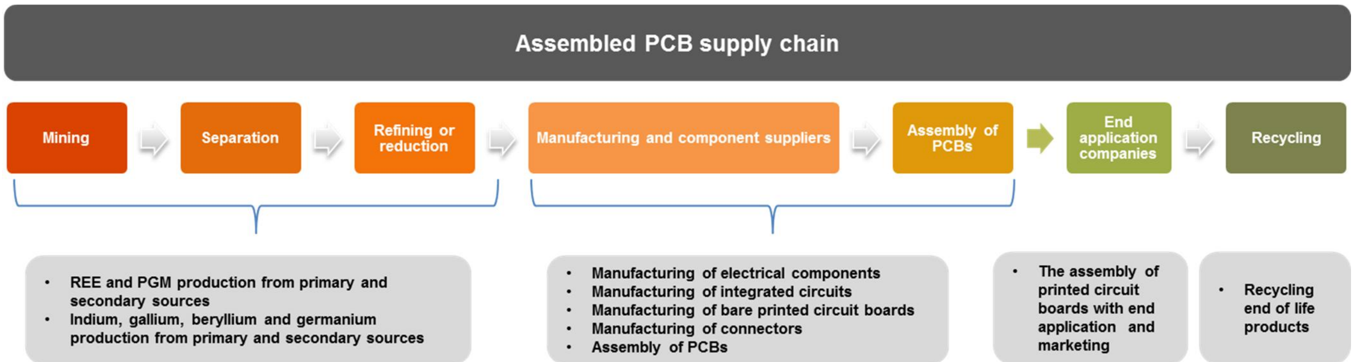


Figure 35: Supply chain of assembled printed circuit board.

The supply chain can be roughly divided to four different stages. The first stage is raw material production from primary or secondary sources. The material can be in the form of pure metal powder or alloy. The second stage is the manufacturing of different components. Component manufacturing includes components such as capacitors, semiconductors, resistors and bare printed circuit boards as well as integrated circuits. These integrated circuits may already include some capacitors, resistors or transistors within. As a result of the second stage, an assembled circuit board including components mounted with connectors on a bare printed circuit board is produced. The third stage of the supply chain is the assembly of end application. The final stage of the supply chain is the recycling end of life products.

The main actors in the supply chain of assembled PCB is presented in Figure 36.

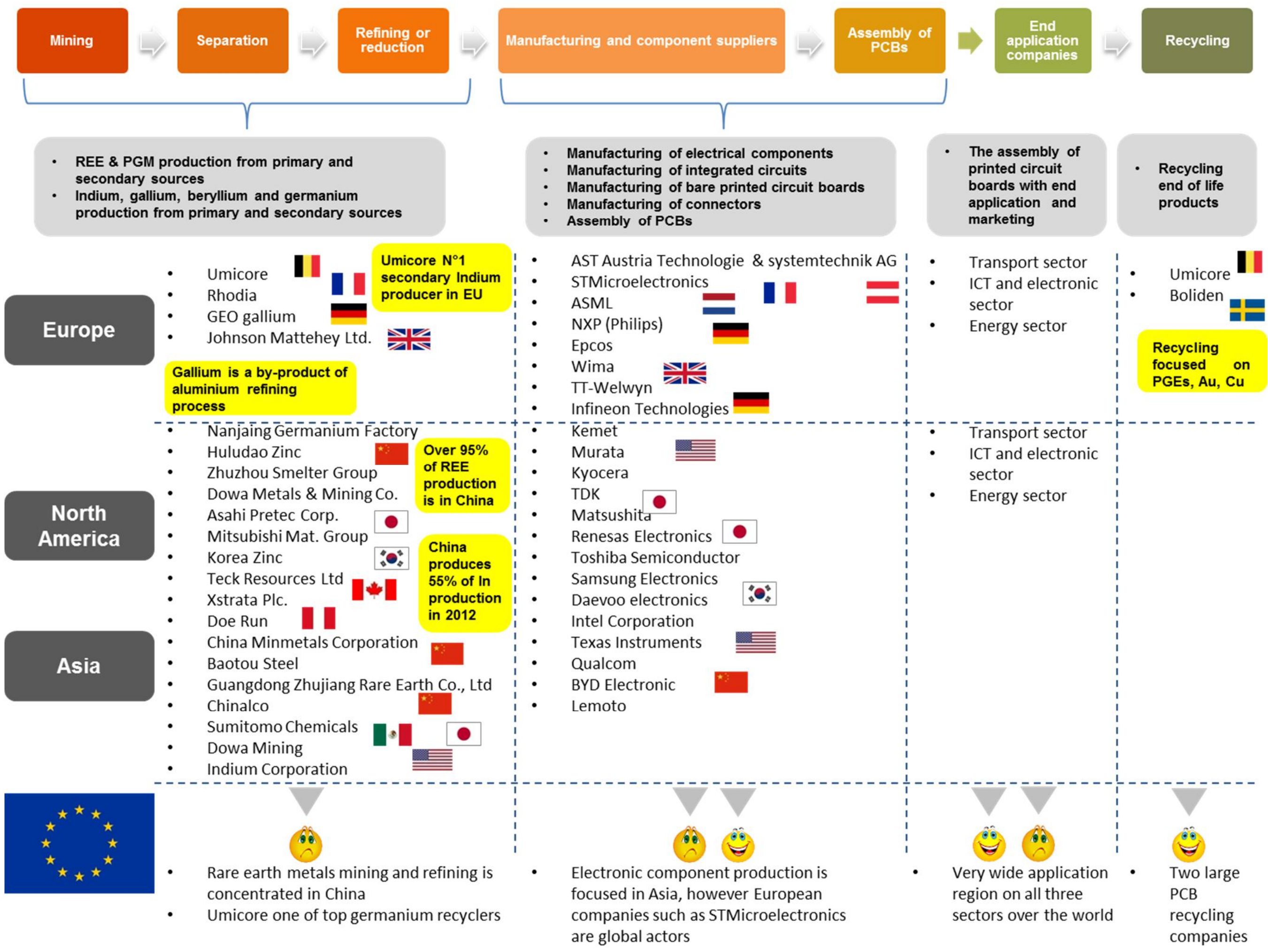


Figure 36: The main actors in assembled PCB supply chain (focus on component manufacturing).

<u>Jobs involved in EU</u>

Based on Eurostat's structural business statistics, the manufacture of electronic components sector (including electronic circuit and semiconductor production), employed 220,000 people in 2010 within Europe. The largest employing country was Germany (56,000 jobs). The next largest employing countries were Italy, France and the United Kingdom (30,000, 27,000 and 21,000 jobs respectively). In addition, manufacture of loaded electronic boards sector (including bare printed circuit board production) employed 73,000 people in 2012 within Europe. France employed approximately 24,000 people while the next largest employing country was Germany providing employment for around 18,000 people. As for connectors which belong to manufacturing of wiring devices sector around 92,000 people were employed. The largest employing country was Germany (57,000 jobs) followed by France (12,900 jobs) and Italy (6,900 jobs). Finally the manufacture of other electronic equipment sector (including capacitor production) employed approximately 180,000 persons in 2010 within Europe. Germany provided employment for over 50,000 people while Italy as second largest employing country employed approximately 34,000 people. (Eurostat 2010b)

EUROSTAT data interpretation

The quantitative supply chain analysis was carried out on data from Europe's PRODCOM database. More detailed information on the data and application composition can be found in Appendix 7 (Assembled PCB). The data from PRODCOM has been applied to produce supply chain illustration for production with largest producing countries in EU (Figure 37). **However, it is essential to understand that the shares/dimensions of different industries (box sizes) represent the production for the whole industry not only the share which is used in assembled printed circuit board production.**

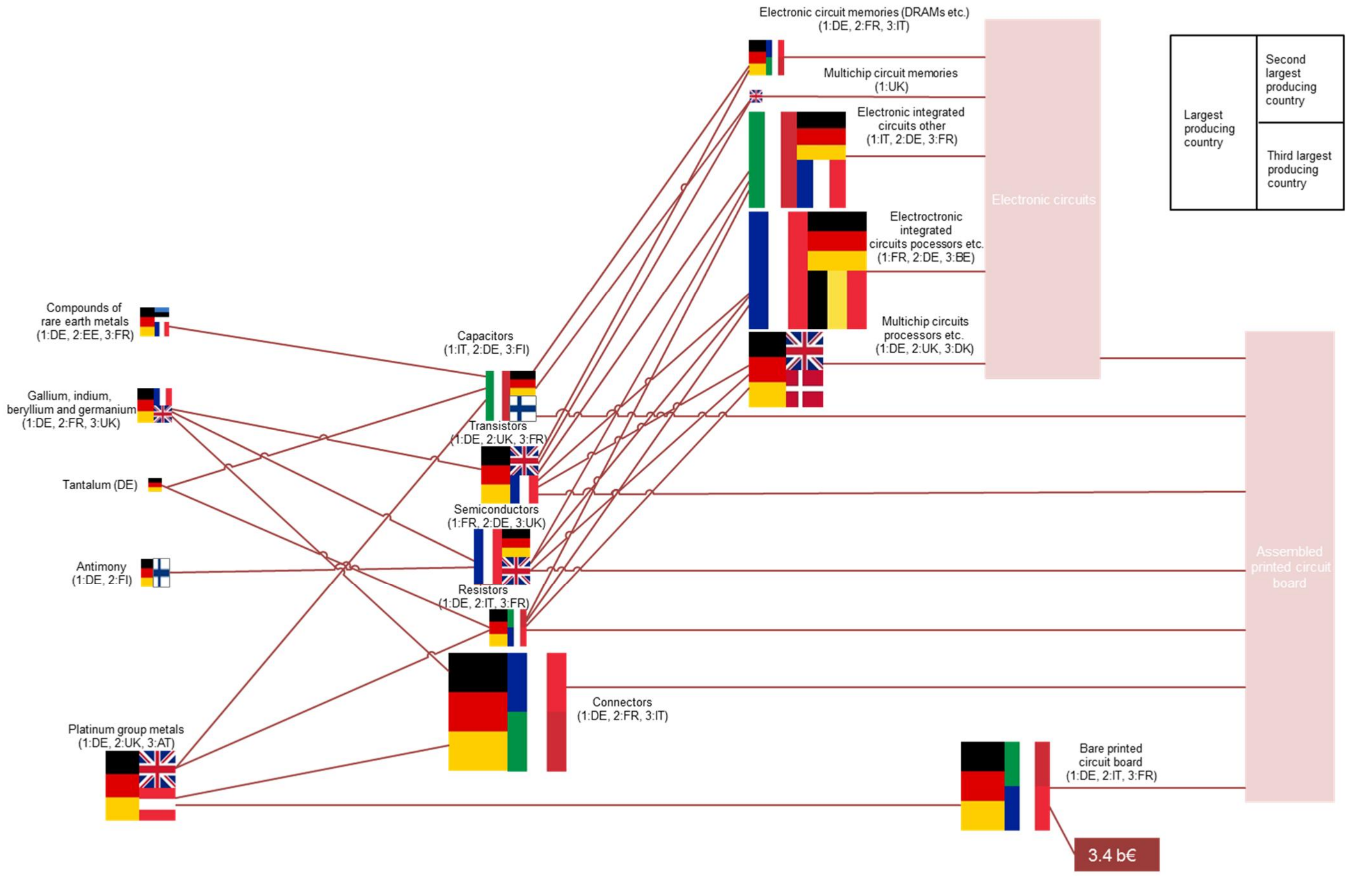


Figure 37: EU production of assembled printed circuit boards and related (sub)-components and materials. Components and end application in pink boxes have no corresponding PRODCOM group and therefore no statistically defined value and are included for completeness. Each box presents the total production value, not the value of components/materials which are used only in assembled PCB applications. In addition, the largest EU producing countries are presented.

The structure of assembled printed circuit board's supply chain differed from previous applications due to the use of PCBs as components, not as end application (Figure 37). The assembled PCBs are used in a wide range of applications such as in computers, televisions, food mixers, washing machines, vehicles and wind turbines. As a result the end application cannot be defined. The production in terms of value is distributed rather evenly between all components in the entire supply chain. However, an increase in production can be detected while moving from materials toward components. Of course some deviations from this trend, such as large platinum group metals production and small multichip memories production, can be detected. Figure 37 show that Europe had significant integrated circuit production, especially multichip and electronic integrated circuit processors are produced. As for memories the production is less.

The production is concentrated mainly in Central Europe. In integrated circuits both Italy and France are large producers due to the factories of STMicroelectronics among others. Other significant component manufacturers are Germany and the UK which also has material production. The UK has platinum group metals production with companies such as Johnson Matthey Ltd while Germany had production of all materials.

The relationship between production, import and export value for all components, materials and the end application is presented in Figure 38. Note the values for components and materials represent the entire industry, not only the share used in assembled PCB.

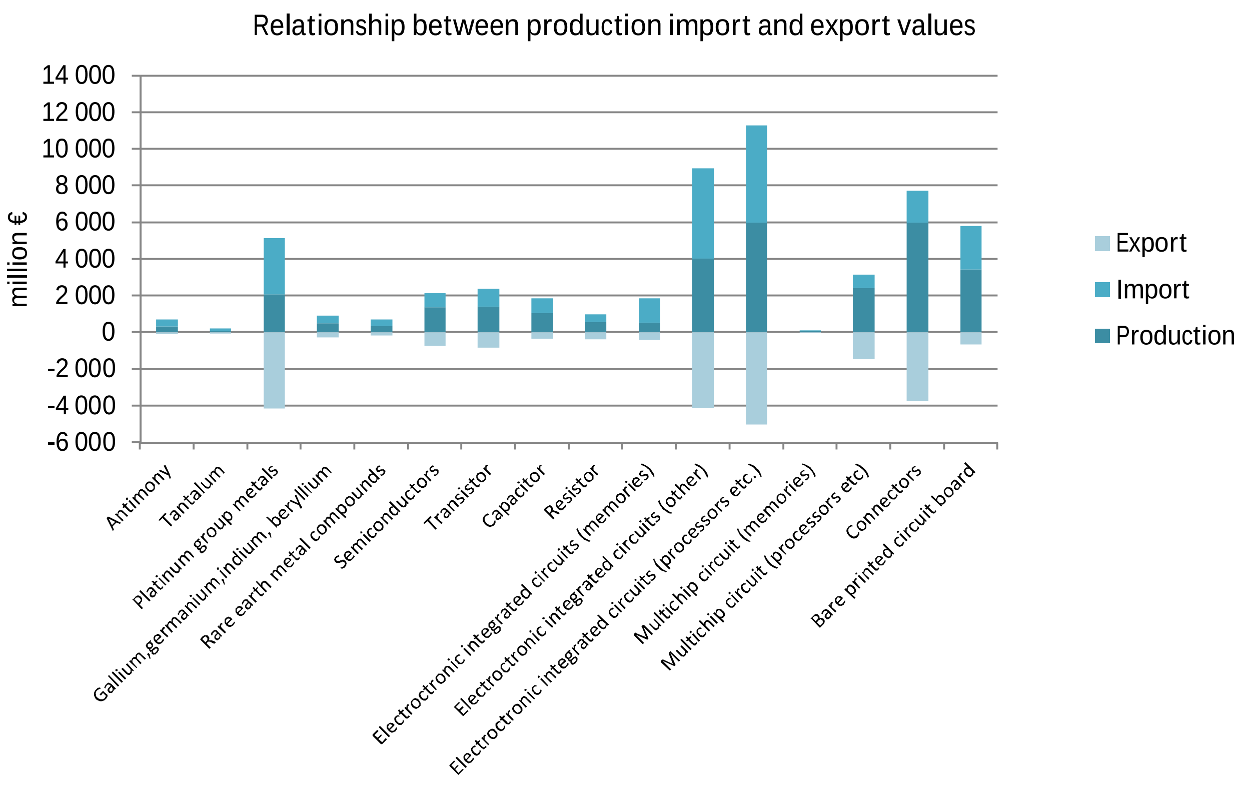


Figure 38: Relationship between production, import and export values for assembled PCB application, components and materials in Europe 2012. **Note** the values for components and materials represent the whole industry, not the share which is only used in assembled PCBs.

In Figure 38 production plus import, which are presented on the positive side of x-axis, represent the cumulative value of articles which are within Europe. Consequently, the value of export is on the negative side and expresses the value of articles which leaves Europe.

Examining Figure 38 it can be noticed that the trade balance (import, production and export) is distributed evenly in both electronic integrated circuit (processors) and electronic integrated circuit (other) groups. This indicates that a large proportion of these components produced in Europe are exported. However, some of the imported components may be re-exported. In addition, the near 70% share of the trade balance comprised of import and production denotes that there is also consumption of these articles within Europe as components. As for bare printed circuit boards nearly 90% the trade balance is comprised of import and production which indicates strong consumption of these articles as components in Europe. Printed circuit boards are often tailor designed for an application and therefore manufacturing of these articles need to be closely linked to the end application. Multichip processors' and connectors' production also exceeded the 50% share of the trade balance. Together with only 30% export share of the trade balance, the consumption of these articles as components in end applications is highly likely. For passive components (resistor and capacitor) only between 15% and 25% of the trade balance comes from export which indicates strong use of EU produced and imported components in further applications within Europe. Raw materials are mainly either produced or imported into Europe. As for exports, platinum group metals make an exception with a large export. However larger export value than production value in platinum group metals, indicated re-export of imported articles. Generally, a country is involved in re-exports if it has a major hub in a transport network that is used to redistribute goods to neighbouring countries. Re-exports can also stem from trading positions, for instance resulting from strategic stockpiling. As for the gallium, indium and germanium material group larger production than import value supports the business analysis where production of these metals from secondary sources in Europe had been identified.

Criticality

<u>Essentiality of the role of CRM</u>

Most of the electronic components attached to printed circuit boards contain at least one CRM (EPOW 2011), but as the information of different CRMs in PCBs is very limited, also the essentiality of these CRMs is hard to define. Although, it seems that at least some CRMs can be replaced.

<u>How will the vulnerability of the application evolve?</u>

As PCBs are needed in almost all electronic products, their demand in the future does not seem vulnerable; on the contrary the development of new products and technologies may increase the market for PCBs. The information about critical raw materials in printed circuit boards is very limited, and thus the vulnerability related to CRM dependence cannot be estimated.

<u>Available substitutes</u>

There are several substitution options for critical raw materials used in printed circuit boards. More specific descriptions of many of these methods are seen in CRM_InnoNet (2013b) report "Raw Material Profiles".

- Antimony: Antimony is used as a dopant in n-type silicon semiconductors. Other, more often used n-type dopants in silicon are phosphorus (P) and arsenic (As). Antimony has lower solubility in silicon than P or As do. Otherwise Sb can be readily substituted by P or As. Flame retardants are sometimes used in the polymeric constituent (e.g. epoxy) of the printed circuit boards (PCB) because the US Safety Standard UL 796 defines test procedure for flammability. Antimony in this use can be replaced by halogen or phosphorus compounds. The same applies to the plastic packaging materials of electronic components. (Ylilammi 2013.) In general, antimony trioxide used in flame retardants can be substituted with selected organic compounds, hydrated aluminium oxide (Salazar & McNutt 2013) or mixtures of zinc and boric oxide (Borax Firebrake ZB 2013).

- Beryllium: Be is a p-type dopant in III-V compounds like GaAs, AlGaAs, InGaAs and InAlAs. It can be replaced by magnesium (Mg) but the amount of dopant materials is very small. (Ylilammi 2013.) The use of nickel and silicon, tin, titanium, or other alloying elements or phosphor bronze alloys can substitute beryllium containing copper alloys, however, performance losses are possible. Beryllium oxide can be substituted with aluminium nitride or boron nitride. (Salazar & McNutt 2013.)

- Gallium: Ga containing III-V semiconductors GaAs, AlGaAs, InGaAs etc. are used in high-frequency transistors, LEDs and solar panels. To some extent Ga can be replaced by aluminium (Al) or indium (In) but the resulting device properties are not identical. (Ylilammi 2013.) Ge is used as an alternative to GaAs semiconductors. Germanium materials used in the electronics industry can be produced at a fraction of the cost compared to GaAs semiconductors. (EPOW 2011.) The substitution of gallium in ICs is currently possible for a limited number of applications, however, the substitution is limited to another CRMs containing material SiGe (CRM_InnoNet 2013b).

- Germanium: Silicon can substitute germanium in some electronic applications (Salazar & McNutt 2013), although this may lead to a performance losses (CRM_InnoNet 2013b). Some metallic compounds can be used for high-frequency electronics (Salazar & McNutt 2013).

- Indium: Indium can be used as p-type dopant in silicon but is seldom used because B, Al, Ga can be used instead (Ylilammi 2013). Tin-based alloys can substitute indium alloys in the least thermally sensitive applications. It is also possible to use tin-alloys for bonding on gold instead of indium alloys. (CRM_InnoNet 2013b).

- Palladium: Palladium or palladium alloys are used as electrode metals in multilayer ceramic capacitors. Silver or nickel can partially or totally replace palladium. Nickel is used particularly in low-voltage capacitors. (Ylilammi 2013.)

- Ruthenium: Oxide compounds of ruthenium are used as resistive material in integrated resistors. Oxides of other metals (Ti, Ta, Ni etc.) can be used to replace Ru but the properties are not identical. Ruthenium alloys are used in electrical contacts because of their good wear resistance. Another alternative is rhodium but it is more expensive. Metallically conducting ruthenium oxide can be used to replace platinum metal electrode in certain microelectronic devices. (Ylilammi 2013.)

- Tantalum: Before Ta capacitors aluminium was used for the same purpose and is still used at higher voltages (Ylilammi 2013). Tantalum can also be substituted with ceramic capacitors and niobium (CRM_InnoNet 2013b).

Environmental

Impact on European policies in case of supply disruption

The environmental impacts related to the PCB supply disruption are not easy to define, as printed circuit board is not an application itself but a component in an electronic device. The supply disruption of PCBs would probably complicate the production of at least some electronic devices, and thus cause indirect environmental impacts.

Innovation

Substitution activities already ongoing

The current trends in printed circuit board design, miniaturization and flexibility, have affected the form and function of PCBs. It seems that R&D projects related to PCBs are focused on component innovations and additive manufacturing, rather than the actual replacement of printed circuit boards.

4.6.3 Assembled printed circuit board – business summary

A summary of business analysis is presented in Table 28.

Table 28: Qualitative summary table of assembled printed circuit board.

Dimension	Criterion	Required input
economic	Economic value of application or area	**The production value in Europe for all type of electronic circuits (incl. multichips) was approximately €13 billion in 2012. As for bare printed circuit boards, passive components (resistors and capacitors) and connectors the production values were around €3.4, €1.6 and €6.0 billion respectively. The production value separately for both transistors and semiconductors was around €1.4 billion. (Eurostat 2012.)**
	Position of EU in entire supply chain	**Europe has electronic component production in terms of value especially in electronic circuits. However, the electronic component industry is wide and dynamic and the leading production is located outside Europe.**
	Jobs involved in the EU	**In 2010 around 195,000 persons were employed in manufacture of electronic component sector. In addition, manufacture of loaded electronic boards sector employed 73,000 people while the manufacture of other electronic equipment sector employed around 180,000 people. The manufacturing of wiring devices employed around 92,000 people. (Eurostat 2010b.)**
criticality	Essentiality of the role of CRM	**No specific information found. Some CRMs can be substituted.**
	How will the vulnerability of the application evolve (as a result of RM and market developments)?	• **The development of new products and technologies is likely to keep PCB demand strong in the future.** • **The information about critical raw materials in printed circuit boards is very limited, and thus the vulnerability related to CRM dependence cannot be defined.**
	Available substitutes?	**Several options for substitution. See also CRM_InnoNet (2013b) report "Raw Material Profiles" for substitution options.**
environmental	Impact on European policies in case of supply disruption	**The environmental impacts related to the PCB supply disruption are not easy to define, as printed circuit board is not an application itself but a component in an electronic device. The supply disruption of PCBs would complicate the production of electronic devices, and thus cause indirect environmental impacts.**
innovation	Substitution activities already ongoing? What is the status of that research?	**Not found.**
	Principle of substitution: is substitution conceivable?	**-**
	Opportunity for Europe	**Additive based manufacturing as well as production of flexible and printed circuits may create possibilities for Europe. In addition, greener solutions both in the components and products as well as in the manufacturing process compose opportunities.**

5 Conclusion

The ICT and electronics sector is a rapidly changing industry segment, in which production is strongly focused in Asia. However, the production of some applications does also exist in Europe. Based on the supply chain study carried out for five applications and assembled PCBs it can be concluded that the ICT and electronics industry in Europe is concentrated mainly to end product/application production.

The MRI application is one of the key market areas in medical imaging industry. The market revenue of MRI in Europe was approximately €670 million in 2011 and the sector of manufacturing of irradiation, electro medical and electrotherapeutic equipment employed around 46,000 people in Europe in 2010. Two European companies (Siemens Medical solutions and Philips Healthcare) are amongst the top three MRI producers and North American company GE also has manufacturing in Europe. The market segment in Europe is highly competitive and is driven by high pricing pressure. In addition, MRI system manufacturing is a knowledge intensive industry and therefore the risk of moving it outside Europe can be considered not as high as in component or simple product manufacturing. Based on data from Eurostat, production in Europe is distributed over the whole supply chain. The main CRM dependencies are use of niobium in superconducting magnets and REEs as well as beryllium in components. In addition, a small share of the assembled MRI systems contains permanent magnets, in which REEs are used. Leading European producers have superconducting magnet production of their own, and European companies are also strong in production of electronic components for professional applications. The manufacturing of all kinds of magnets (including superconducting and permanent magnets) in the EU is minor compared to, for example, electronic component production or production of the MRI machine itself. Availability of raw materials could be a potential CRM related bottleneck. Both niobium and REE production are concentrated in one country (Brazil and China recpectively). In terms of substitution of the NdFeB magnets in MRI applications, the on-going shift from low magnetic field applications (which use NdFeB magnets) to high field applications (which use superconductive Nb-alloys) may decrease the reliance of NdFeB magnets in MRI applications. As for superconducting magnets containing niobium, MgB_2-based MRI magnets and high temperature superconductors (HTS) have been studied and developed aiming to substitute niobium-dependent systems. However, both technical and cost related issues need to be resolved before MgB_2- and HTS based MRI systems can commercially substitute current market-leading MRI systems.

LED lighting is a rapidly growing segment substituting conventional lighting. Due to the decreasing manufacturing costs, low energy consumption and small size, the LED segment will continue to grow. In 2011 the general lighting market size in Europe was around €1 billion and the manufacturing of electronic lighting equipment sector employed around 155,000 people in 2010. Two European companies are amongst the top LED producers and there is also a large number of SMEs focused on innovative LED applications. It has been estimated that the market share of LED lighting will increase to 40% by the year 2016 and to over 60% by 2020. Examining the data from Eurostat it can be noticed that LED lighting production in Europe is focusing on end production while the manufacturing of LED diodes is concentrated outside of Europe. The high import value and low export value of LED diodes in Europe supports this scenario. The market analysis highlighted that Osram was the only European LED die manufacturer with a 7% global market share. Therefore, the LED lighting segment in Europe is dependent of LED die production causing a potential bottleneck in the supply chain.

Small amounts of critical raw materials (e.g. Ga, In, Y, Eu, Ce, Tb, Lu) are essential for the functionality of LEDs. As for substitution, new technologies such as OLEDs are already studied, piloted and even commercialized, however it will take some time before all LED's in different lighting systems are replaced.

Optical fibres enable the global data transmission underpinning the modern digital economy. In addition, they are used in sensors, fibre lasers, special illumination applications and decorative applications. In 2012 the production of optical fibres and cables (including hardware) was approximately €1.4 billion in Europe and the manufacturing of fibre optic cables sector employed around 9,500 people in 2010. The demand for optical fibre is expected to grow due to the building of new networks both in developed and developing countries. Based on the data from Eurostat, the production value in Europe increased when moving along the supply chain towards the end product. However, the difference between the value of end production industry and component/material industry is not as great as in LED lighting applications indicating that as distinct bottleneck cannot be detected in the supply chain of optical fibre. The main CRM used in the production is germanium, which is essential for the functionality. About 30% of germanium production is consumed in fibre optics. Some substitution activities exist in the optical fibre segment, for example replacing germanium with erbium, tellurium or phosphorous. However, these substitutes either suffer from performance losses, are still in the research stage or their ability to fulfil the product requirements or industrialization capability is unclear. In addition, the high requisite production volume puts certain pressures on the substitution potential especially in the case of fibre optics.

Different kinds of display-based devices are widely used for communication, education as well as for entertainment purposes. Televisions, mobile phones and computers are everyday examples of display-based devices, but displays and screens are also used in wide-ranging other consumer products and in industry, automotive and medical applications. The demand for LCD displays is estimated to grow in the future. However, a shift from CCFL to LED backlighting and OLED based display technology is underway. In 2012 the production of all kind of displays, visual signal receiver units, monitors and projection equipment in Europe was around €14 billion. In addition, the manufacturing of consumer electronics and other electrical equipment sectors employed a combined total of 262,000 people in 2010. In the European supply chain of displays the production value is concentrated at the end application production. In addition, high import values and low export values indicate that displays are consumed in Europe. However, the data from Eurostat also includes information on projection equipment and other sound and visual signal receivers resulting in higher values. Therefore specific production values for displays, televisions, monitors and screens could not be identified. From other market data and company websites it can be seen that several large international TV/display producers have factories in Europe, and there are also smaller European producers. Displays are dependent on several critical metals, such as indium, REEs and PGMs. Especially indium-tin oxide is an essential component in LCD screens and with no viable substitution option indium scarcity may create a bottleneck for LCD production. In terms of technology substitution OLED based display technology is estimated to take over the markets by the end of 2020. However, OLED technology is not entirely CRM free even though the amounts required are less than in conventional LED technology.

In this study, washing machines are used as a representative example from the large household appliances sector. Washing machine markets are estimated grow modestly in future. The production value of washing machines in Europe was around €4.6 billion in 2012, the largest production value from the major appliances sector which also includes refrigerators and air conditioners. In addition, the manufacture of electric domestic appliances sector employed around 195,000 people in 2010. The dependence of CRM in all washing machines is not clear since some electric motors in washing machines use NdFeB magnets while others use conventional magnets. However, due to the pressure to decrease energy consumption in large household appliances, and increase in the use of NdFeB magnet based motors in washing machines has been observed in Japan. Similar trends can be assumed to be taking place in Europe. As for the supply chain of washing machine in Europe, production exists both on component and end application level. Availability of permanent magnets may be a bottleneck, but this would only disrupt the production of energy efficient washing machines as washing machines with traditional motors could still be produced. The next developments in washing machine technology will focus on changing and improving whole washing processes with, for example, steam or negative ion based washing.

Assembled printed circuit boards (assembled PCB) are crucial components in almost every application regardless of the sector in which the end application belongs. Therefore the supply chains of all three sectors studied (ICT and electronics, energy and transport) are dependent on assembled PCB. The market of electronic components is highly dynamic, fragmented between many companies and competitive. As a result, market leaders comprise only small shares of the entire markets. The production of electronic components is concentrated mainly in Asia. However, the European electronic component production is significant in terms of European economy. For example, based on the data from Eurostat the combined production value of all electronic components (incl. connectors, bare printed circuit boards, passive and active components) was around €25 billion in 2012. In addition, the manufacture of electronic component sector itself employed around 195,000 people in 2010 where as the manufacture of loaded electronic boards sector employed 73,000 people. As a result the importance of manufacturing electronic components for Europe both in terms of jobs and value is significant even though the main production takes place outside Europe. The components contain usually at least one CRM (e.g. Ga, Ru, Pd, Ta, Be) due to their physical properties and functions. As a consequence of miniaturization of components, more efficient assemblies can be produced. However, a vulnerability assessment on component specific CRM dependencies cannot be carried out, since the detailed information on components is limited and the components are designed based on the specific requirements of the customers. The current trends in printed circuit board design, miniaturization and flexibility, have affected to the form and function of PCBs.

A summary table of Europe’s position in the applications’ supply chains and jobs of the sectors in which the production belongs to is presented in Table 29.

Table 29: A summary of Europe's position in supply chains and jobs.

Supply chain	Application/Component/ Material	MRI	LED	Optical fibre	Display and screens	Washing machines	Jobs
End product	MRI	green					red
	LED lighting		green				green
	Optical fibre			green			red
	Display and screens				green		orange
	Washing machine					green	green
Component	Display	green			green		orange
	Electric motor	orange				orange	green
Sub-component	Electrical circuit	green			green	green	green
	Transistors	orange	orange		orange	orange	green
	Capacitors	orange	orange		orange	orange	orange
	Resistors	orange	orange		orange	orange	orange
	Bare printed circuit board	green	green		green	green	orange
	Connectors	green	green		green	green	orange
	Permanent magnet	red			red	red	green
	Conducting electrodes (ITO)	orange			orange		green
	Fluorescent tubes	orange			orange		orange
	Semiconductor light-emitting diodes (LED)	red	red		red		green
Material	Compounds of rare earth metals	orange	orange		orange	orange	orange
	Tantalum	red	red		red	red	red
	Beryllium, gallium, germanium, indium and niobium	orange	orange	orange	orange	orange	red
	Platinum group metals	orange	orange		orange	orange	red

		Jobs
green	Production in EU and rather good position in global production/jobs in EU (the sector in which application/component/material manufacturer belong to)	> 200 000
orange	Some production in EU, however main production outside EU/jobs in EU (the sector in which application/component/material manufacturer belong to)	50 – 200 000
red	Not much production in EU /jobs in EU (the sector in which application/component/material manufacturer belong to)	< 50 000

Examining the Table 29 it can be observed that the production in Europe is mainly focused in end products. Comparing the end production with jobs, especially the lighting and domestic appliances sectors employ people in Europe. However, jobs are reported at the sector level and therefore they include jobs which are not directly connected to end application production. At component level especially electronic component manufacturing has an impact on the European economy both in production values and in jobs. Components such as permanent magnets and semiconductor dies are mainly produced outside Europe but are still important components in some of the end applications that are produced in Europe. As for materials refining and forming Europe has some production however the main production is located outside Europe. In addition, jobs in materials refining industries are less than in component or end application production.

As a result of this analysis, it appears that nearly all end applications are exposed to CRM issues, mainly through the electronics within the applications. Indirect exposure can also be identified for MRI, washing machine, displays and LED lighting due to the reliance of magnets (both superconducting and NdFeB) and semiconductor dies (LED). However, the production of these components is mainly situated outside the Europe which widens the direct reliance of CRM. As for optical fibre due to the reliance of germanium dopant in the fibre and with no commercial substitution option viable, germanium scarcity may create a potential bottleneck for optical fibre production.

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Appendix 1 (methodology)

Terms and definitions

Definitions related to analysis methodology are presented below:

Centralized data source

The centralized data sources include statistical databases, such as: PRODCOM (Eurostat database providing statistics on the production of manufactured goods), SBS (Structural Business Statistics), BACI/COMTRADE (International Trade Database/The United Nations Commodity Trade Statistics Database, EXIOBASE (global, Multi-regional Environmentally Extended Supply and Use / Input Output database by the University of Leiden).

Application

The special use or purpose to which a technology or product is needed. For instance, “data storage” is an application.

User sector

In this report the user sectors are: energy, ICT and electronics and transport (aerospace and automotive)

PRODCOM sector

The sectors defined in PRODCOM database, for example “Manufacture of electrical equipment”, “Manufacture of machinery and equipment”

Product group

When the centralized data sources are used in the statistical analysis, “product group” defines what can be considered an application/product/technology. For instance, if “data storage” is an application (see definition above), the corresponding product group classification is “Digital Processing Units Whether Or Not Presented With The Rest Of The System Which May Contain Storage Units” (and other groups that have similar elaborate descriptions).

Statistical analysis

The statistical analysis of supply chains contains:

- A majority of raw materials and intermediate products related to the product group and containing CRM;
- Production, import and export of raw materials and intermediates expressed in €. If relevant volumes in tons of raw materials are added;
- A maximum of 3 EU countries that supply the largest share (in €) of parts of the value chain.

Business analysis

A partly quantitative, partly qualitative report and a summary table as addition to statistical value chain analysis (see above). It provides essential information for prioritisation of the applications (see Table 31) and insights on the value chain analysis in the CRM_InnoNet project. The report lists individual stakeholders (companies) if feasible.

Introduction

The aim of this work is to create more understanding about the relevance of critical raw materials (CRM)[1] for the European economy and to give indications of which applications could be under threat. On account of economic importance the following user sectors have been selected for analysis: Energy, ICT and electronics and transport with specific emphasis on aero and automotive transport. Selected key applications from each sector were assessed by examination of the 'CRM supply chain' for each application. When starting the work, the objective was to make a value chain analysis of selected applications. However it was found that using the data sources available, it was not possible to get information on the value addition of components used in the end applications which is required for a full value chain analysis. Therefore it was chosen to rather make an analysis of the supply chains as a way to get at least partial information on the value chain.

This 'CRM supply chain analysis' examined the economic importance, CRM availability and strategic relevance over each stage in the production of the selected application. In addition, analysis of current risk provision strategies and opportunities for industries was completed. The full assessment methodology is presented in the summary report.

The value chain analysis is part of the project CRM_InnoNet (Substitution of Critical Raw Materials). The data produced will (together with the additional data produced in the bottom-up-analysis of the CRM-landscape[2]) be used in prioritisation of the applications for elaboration of a roadmap for the substitution of Critical Raw Materials.

Supply chain analysis methodology

In developing a methodology for analysing the value chains of applications the following factors were considered to be important:

- Economic relevance to Europe.
  The focus was in understanding where in the supply chains of applications (Figure 39) the value for Europe is produced, creating basis for assessment of the economic vulnerability of the applications. In previous studies, economic aspects have been discussed only superficially. The information needed was compiled by analysing the supply chains for the following quantities: production in EU countries, import to and export from these countries.

- Transparency and transferability.
  In all three user sectors critical raw materials are used in a wide variety of different applications. In order to produce reliable and comparable results, the same analysis methodology needs to be applicable to all three user sectors and common data sources need to be used. Therefore the quantitative economic analysis was performed using statistical data sources.

[1] The starting point in this work was the list of 14 Critical Raw Materials highlighted in the EC's report: Critical Raw Materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials. Version of 30 July 2010.
[2] CRM_InnoNet, Deliverable report D3.3. Raw Material Profiles. September 2013

- CRM relevance.
  Most of the applications are composed of numerous components or intermediate products, making the supply chains of the applications complex. As this study aims to identify bottlenecks arising from lack of availability of critical materials, only the parts of the value chain containing critical raw materials were analysed.

In addition to analysis of current economic relevance, it is important to point out how the vulnerability of the applications is expected to develop in the future, and how the potential disruption would affect Europe's ability to meet strategic targets. It is not possible to assess such factors on the basis of current market data so a qualitative approach using market and sector reports was adopted.

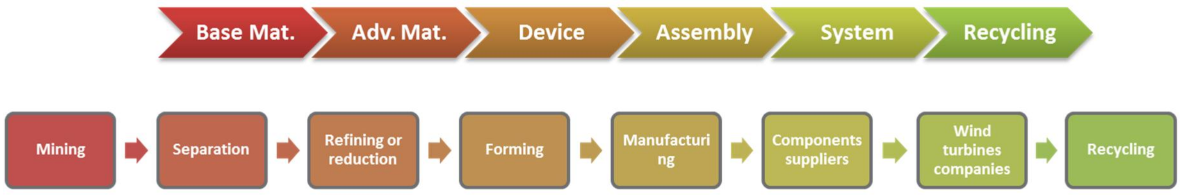

Figure 39: Main stages of a supply chain. Supply chain of wind turbines is presented as an example

In order to highlight the most important applications for the European economy, screening was required to reduce the number of applications to a manageable number for in-depth study via a supply chain analysis. Therefore a two phase approach was followed:

Phase 1: screening

The first phase was the identification of suitable applications to progress to full supply chain analysis from a complete list of applications relevant to a particular user sector. The applications were screened by considering three criteria to assess CRM dependency and economic importance to Europe.

Phase 2: supply chain analysis

The second phase was the full CRM supply chain analysis of the selected applications. The full analysis approach was composed of a statistical analysis (statistical analysis) and examination of supporting market and technical qualitative and quantitative data by experts (business analysis).

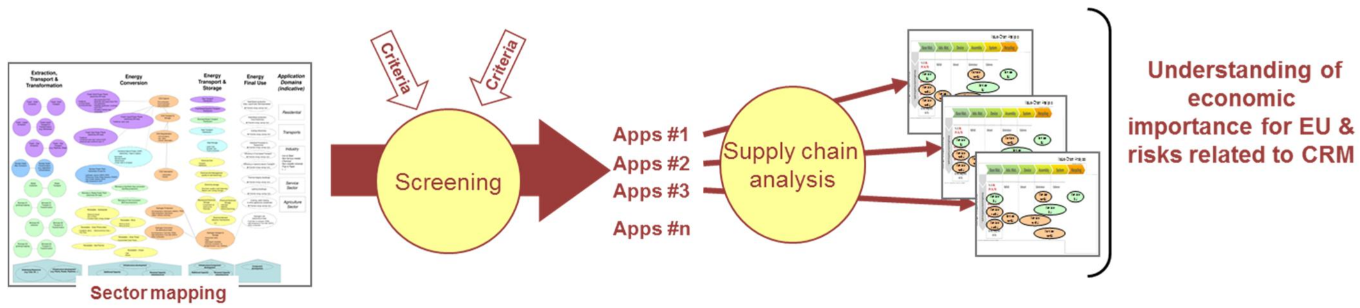

Figure 40: Approach to selection of applications for supply chain analysis.

Because the selection of applications for supply chain analysis and the implementation of the analysis had to be made in a uniform and transparent way, the same analysis methodology was applied for all three user sectors. The step by step description of the analysis methodology is presented in the following. The definitions of the terms used can be found on at the start of Appendix 1.

Description of the methodology

Phase 1: screening

Step	Description
1	The scope of the user sector is defined and a 'long list' of relevant applications is created. (Applications with no CRM dependence or very small markets are not included).
2	The statistically defined product groups corresponding to the applications on the long list are defined using CPA (Statistical classification of products by activity) and HS (Harmonized Commodity Description and Coding System) classifications, and the products are analysed for EU share of production and EU consumption/use using centralised data bases (PRODCOM).
3	The most relevant applications are selected for full supply chain analysis by evaluation against three criteria: A. Are CRM used in the supply chain of the application? This has been pre-evaluated during step 1 and is verified here. B. Does the EU produce at least 25% of the value (x) that is consumed/used of this product within the EU? The value x = (EU production)/(EU production + import) is calculated using data extracted from the PRODCOM data base. C. In order to ensure that the biggest EU industries in the three user sectors are represented, the total size of EU production of the product should have at least a share of 0.2% in the total output of the representative PRODCOM sector. The limiting value has been determined so that for the smallest sector the threshold would be at least €500 million. Consequently for the largest sector the threshold is around €1,100 million. PRODCOM values are used in calculation. The order of magnitude of the European market for this product should be stated. In addition, in order to ensure the comparable complexity of products, it is recommended that the products should have minimum four and maximum twenty five supply chain entities.
Applications that meet the three criteria described above progress to phase two, full supply chain analysis.	

Phase 2: supply chain analysis

A 'structural composition' i.e. a list of the CRM containing components and materials in the product is produced (see Table 30).

Table 30: Excel table used for description of the structural composition of an application (Example: light-emitting diode).

Light emitting diode (LED)	CRM content	Comments
LED module		
LED		
Semiconductor die	In, Ga	
Phosphors	Ce, Y, Tb, Lu, Eu, Gd	
Electronics		
Printed circuit board		
Plating	Pd	Not very common to use Pd as plating, generally Ni/Cu and Au are used
Components		
Capacitors	Ta, Pd, Nb	
Resistors	Ta, Ru	
Semiconductors	Ga, Ge, In, Sb	
Transistors	Ga, Ge	
Connectors	Pd, Ru, Be	
Cables		

1. In order to enable statistical analysis, a list of comparable raw materials and intermediate products as defined by statistical classification (CPA and HS classification) is produced. This list represents most relevant parts of the supply chain attached to the application.

2. Quantitative and qualitative market/product information (such as sector reports, company reports, data from strategy consultants, interviews, etc.) is collected and used as input for the Business analysis part of the work. The aim of the business analysis is to complement the information produced by statistical analysis and to enable comparison between the centralized and other data sources. The topics to be discussed in the business analysis are presented in Table 31. The amount of jobs is collected from the statistical databases.

Table 31: The topics to be discussed in the business analysis report.

Dimensions	Sub-criteria
Economic	Economic added value of application in Europe Main actors in the supply chain
	Jobs involved in the EU (excluding indirect jobs)
Availability	Amount of CRMs involved
	Expected future market development
	CRM function
	Availability and status of substitutes
Strategic Relevance	Associated to EU policies for CRMs supply, or specific application development

3. Data from centralised sources is collected and analysed for every part of the statistically defined supply chain of the selected products. The following methodology is used:
   a) Total EU and EU country level production, export and import data is extracted from PRODCOM and BACI/COMTRADE data bases

b) Using the statistical data, tables or graphs are produced summarising the following information for every part of the supply chain: Total EU production, import and export, 3 major EU producer countries, production and trade balance in these countries.
c) The blanks in statistical data are filled using the general market data produced by Business supply chain analysis, if available.

4. For comparison and verification of the results, the statistical supply chain data is matched with specific market/product information and any potential discrepancies discussed.

5. The application specific results of the business analysis (the information presented in Table 31), and those of the analysis (graphical presentation of the EU production, export and import data) are reported. The interpretation of the results is discussed in sector specific reports (D1 – D3) and in Chapter 5 of summary report.

Appendix 2 (MRI data)

The structural composition of MRI and corresponding PRODCOM groups is presented in Table 32.

Table 32: Composition of MRI and corresponding PRODCOM groups.

Component	Typical material involved	CRM Content	Comments	Identified PRODCOM categories
Magnetic resonance imaging (MRI)				26601115 Apparatus based on the use of X-rays, for medical, surgical, dental or veterinary uses (including radiography and radiotherapy apparatus)
Magnet unit				
Permanet magnet				25.99.29.95 Permanent magnets and articles intended to become permanent magnets, of metal
Iron boron magnets				
$Nd_2Fe_{14}B$		Nd, Dy	NIB magnet contains also small ammount of Dy,Pr and Tb	20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
Gradient coils	Cu, Al and epoxy			
Radiofrequency coils	Cu, Al and epoxy			
Electric motors				
Permanent magnet			Different kind of motors are used to move units/parts	25.99.29.95 Permanent magnets and articles intended to become permanent magnets, of metal
Iron boron magnets				
$Nd_2Fe_{14}B$		Nd, Dy		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
Superconducting magnet/wire				25.99.29.95 Permanent magnets and articles intended to become permanent magnets, of metal

				Nb-Ti alloy		Nb		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
	Electronics							
		Printed circuit board (bare without components)						26121020 - Bare multilayer printed circuit boards 26121050 - Bare printed circuit boards other than multilayer
			Plating					
				Palladium		Pb	Not very common to use Pd as plating	24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
		Components						
			Capacitors					27905220 - Fixed electrical capacitors, tantalum or aluminium electrolytic (excluding power capacitors) 27905240 - Other fixed electrical capacitors n.e.c. 27905300 - Variable capacitors (including pre-sets)
				Tantalum		Ta		24.45.30.23 Tantalum and articles thereof (excluding waste and scrap), n.e.c.
				Palladium		Pd		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
				Neodynium		Nd		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
			Resistors					27906037 - Fixed electrical resistors for a power handling capacity > 20 W (excluding heating resistors and fixed carbon resistors, composition or film types) 27906035 - Fixed electrical resistors for a power handling capacity <= 20 W (excluding heating resistors and fixed carbon resistors, composition or film types)
				Tantalum		Ta		24.45.30.23 Tantalum and articles thereof (excluding waste and scrap), n.e.c.
				Ruthenium		Ru		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)

			Semiconductors						26112260 - Semiconductor devices (excluding photosensitive semiconductor devices, photovoltaic cells, thyristors, diacs and triacs, transistors, diodes, and light-emitting diodes) 26112180 - Semiconductor thyristors, diacs and triacs 26112120 - Semiconductor diodes
					Gallium		Ga		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
					Germanium		Ge		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium) 20.12.19.50 - Lithium oxide and hydroxide; vanadium oxides and hydroxides; nickel oxides and hydroxides; germanium oxides and zirconium dioxide
					Indium		In		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
					Antimony		Sb		20.12.19.75 Antimony oxides 24.45.30.47 Zirconium and articles thereof (excluding waste and scrap), n.e.c.; antimony and articles thereof (excluding waste and scrap), n.e.c.
				Transistors					26112150 - Transistors, other than photosensitive transistors
					Gallium		Ga		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
					Germanium		Ge		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium) 20.12.19.50 - Lithium oxide and hydroxide; vanadium oxides and hydroxides; nickel oxides and hydroxides; germanium oxides and zirconium dioxide

Electronic circuit				An integrated circuit, commonly referred to as an IC, is a microscopic array of electronic circuits and components that has been diffused or implanted onto the surface of a single crystal, or chip, of semiconducting material such as silicon. In an integrated circuit, electronic components such as resistors, capacitors, diodes, and transistors are formed directly onto the surface of a silicon crystal.	26113003 - Multichip integrated circuits: processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits 26113006 - Electronic integrated circuits (excluding multichip circuits): processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits 26113023 - Multichip integrated circuits: memories 26113027 - Electronic integrated circuits (excluding multichip circuits): dynamic random–access memories (D–RAMs) 26113034 - Electronic integrated circuits (excluding multichip circuits): static random–access memories (S–RAMs), including cache random–access memories (cache–RAMs) 26113054 - Electronic integrated circuits (excluding multichip circuits): UV erasable, programmable, read only memories (EPROMs) 26113065 - Electronic integrated circuits (excluding multichip circuits): electrically erasable, programmable, read only memories (E^{2}PROMs), including flash E^{2}PROMs 26113067 - Electronic integrated circuits (excluding multichip circuits): other memories 26113091 - Other multichip integrated circuits n.e.c. 26113094 - Other electronic integrated circuits n.e.c.
	Capacitors		Ta, Pd, Nd	Look at capasitors	
	Reistors		Ta, Ru	Look at resistors	
	Semiconductors		Ga, Ge, In, Sb	Look at semiconductors	
	Transistors		Ga, Ge	Look at transistors	
Connectors					
	Copper wire connectors				27331360 - Prefabricated elements for electrical circuits for a voltage <=1kV 27331370 - Connections and contact elements for wires and cables for a voltage <= 1 kV 27331380 - Other apparatus for connections to or in electrical circuit, voltage <= 1000 V
		Palladium plating	Pd		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
		Beryllium copper alloy	Be		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)

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				Ruthenium alloy			Ru		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
	Display								27902020 - Indicator panels incorporating liquid crystal display (LCD) 27902050 - Indicator panels incorporating light emitting diodes (LED) 26.20.17.00 Monitors and projectors, principally used in an automatic data processing system 27.90.20.80 Electrical apparatus for sound or visual signalling, n.e.c.
		LCD display							
			Housing			Plastic			
			Frame			Al, Mg			
			LCD module						
				Glass substrate		Glass etc.			
				Liquid crystal		Polymers			
				Conductive electrodes					22213090 - Plates, sheets, film, foil and strip, of non-cellular plastics, n.e.c., not reinforced, laminated, supported or similarly combined with other materials (excluding self-adhesive products, floor, wall and ceiling coverings of HS 39.18 and sterile surgical or dental adhesion barriers of CN 3006.10.30)
					ITO		In		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
				Orientation films		Polyamidi or carbon			
				Color filter		Pigments, black matrix etc.			
			Films			Polymers			
			Backlight					Backlight can be produced either by fluorescent tubes or LED	
				Fluorescent tube					27401510 - Fluorescent hot cathode discharge lamps, with double ended cap (excluding ultraviolet lamps) 27401530 - Fluorescent hot cathode discharge lamps (excluding ultraviolet lamps, with double ended cap)

					Phosphorus			Ce, Y, Tb, La, Eu, Gd, Pr		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
				LED						26112220 - Semiconductor light emitting diodes (LEDs)
					Semiconductor chip					
						Indium		In		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
						Gallium		Ga		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
					Luminescent substance					
						Carrier medium		Gd, Y		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
						Dopant		Ce, Eu		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
			Loudspeakers						Some displays may have loudspeakers mounted	
				Magnets				Nd	Look at MRI application	20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals

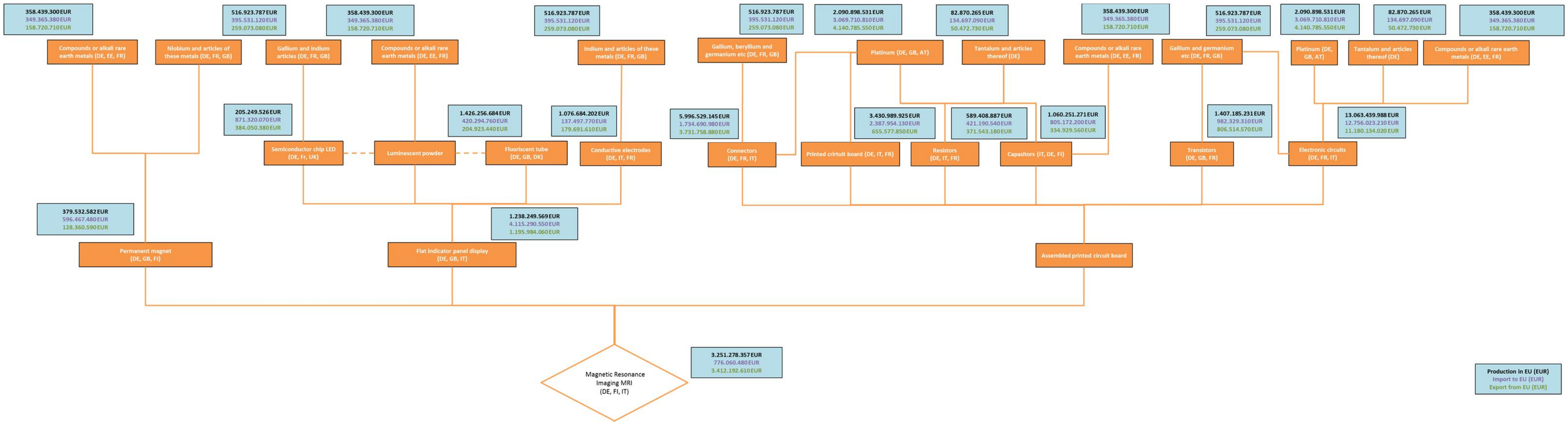

Figure 41: Quantitative supply chain analysis of MRI based on data from PRODCOM.

Appendix 3 (LED data)

The structural composition of LED lighting and corresponding PRODCOM groups is presented in Table 33.

Table 33: Structural composition of LED lighting and corresponding PRODCOM groups.

	Typical material involved	CRM Content	Comments	Identified PRODCOM categories
Light emitting diods (LED)				27403910 - Electrical lighting or visual signalling equipment for motor vehicles (excluding electric filament or discharge lamps, sealed beam lamp units, ultraviolet, infrared and arc lamps) 27403200 - Lighting sets for Christmas trees 27403300 - Searchlights and spotlights (including for stage sets, photographic or film studios) 27907010 - Electrical signalling, safety or traffic control equipment for railways or tramways 27907030 - Electrical signalling, safety or traffic control equipment for roads, inland waterways, parking facilities, port installations or airfields
LED module				
LED				26112220 - Semiconductor light emitting diodes (LEDs)
Semiconductor chip				
Indium		In		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
Gallium		Ga		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
Luminescent substance				
Carrier medium		Gd, Y		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals

					Dopant			Ce, Eu		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
			Electronics							
				PCB				Pd	Look at assembled MRI application (Appendix 1)	
				Components				Ta, Pd, Md, Ru, Ga, Ge	Look at assembled MRI application (Appendix 1) (no electrical circuits)	
				Cables			Cu			
				Connectors				Be, Ru, Pd	Look at assembled MRI application (Appendix 1)	

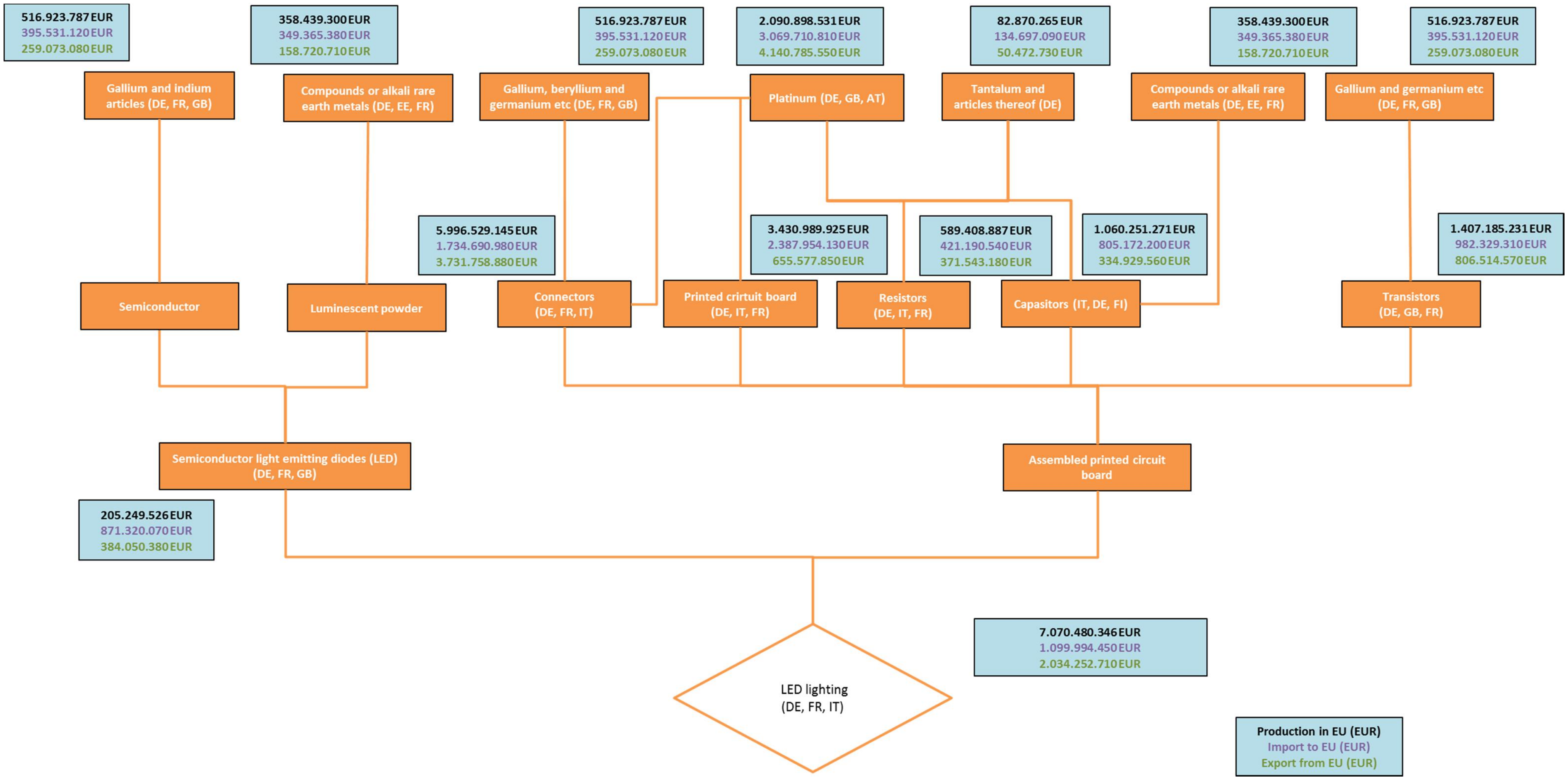

Figure 42: The quantitative supply chain analysis of LED lighting based on information from PRODCOM.

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Substitution of Critical Raw Materials

Appendix 4 (Optical fibre data)

The structural composition of optical fibre and corresponding PRODCOM groups is presented in Table 34.

Table 34: The structural composition of optical fibre and corresponding PRODCOM groups.

	Typical material involved	CRM Content	Comments	Identified PRODCOM categories
Optical fibre cables				27.31.11.00 Optical fibre cables made up of individually sheathed fibres whether or not assembled with electric conductors or fitted with connectors 27.31.12.00 Optical fibres and optical fibre bundles; optical fibre cables (except those made up of individually sheathed fibres)
Optical cable				
Cable core	Metal, glass, plastic			
Sheath	Plastic or metal			
Strength members	Glass fibre, plastic			
Water blocking materil	Tape			
Coated optical fibre				
Glass fibre	SiO_2			23191110 Glass in the mass (excluding glass in the form of powder, granules or flakes)
Dopant		Ge		20.12.19.50 - Lithium oxide and hydroxide; vanadium oxides and hydroxides; nickel oxides and hydroxides; germanium oxides and zirconium dioxide 24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
Connectors	Plastic		Not electrical.	

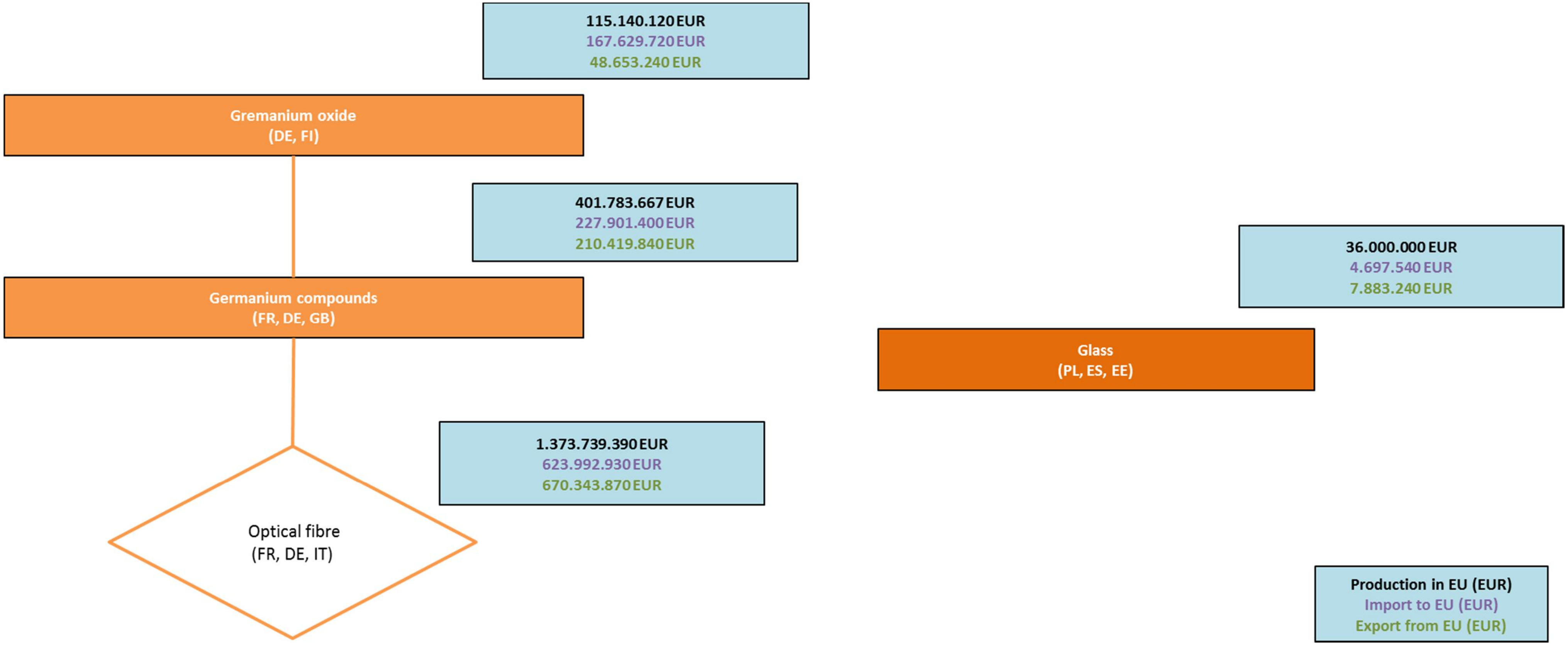

Figure 43: The quantitative supply chain analysis of optical fibre based on information from PRODCOM.

Appendix 5 (Display data)

The structural composition of display and corresponding PRODCOM groups is presented in Table 35.

Table 35. The structural composition of optical fibre and corresponding PRODCOM groups.

	Typical material involved	**CRM Content**	**Comments**	**Identified PRODCOM categories**
Display and screens				27902020 - Indicator panels incorporating liquid crystal display (LCD) 26402090 - Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c. 26402040 - Colour television projection equipment 27902050 - Indicator panels incorporating light emitting diodes (LED) 26.40.20.20 Tuner blocks for CTV/VCR and cable TV receiver units (colour video tuners) (excluding those which isolate high-frequency television signals) 26.20.17.00 Monitors and projectors, principally used in an automatic data processing system 27.90.20.80 Electrical apparatus for sound or visual signalling, n.e.c. 26403460 - Flat panel video monitor LCD or plasma , etc. without tuner (colour video monitors) (excluding cathode-ray tube)
LCD display				
Housing	Plastic			
Frame	Al, Mg			
LCD module				
Glass substrate	Glass etc.			
Liquid crystal	Polymers			
Conductive electrodes				22213090 - Plates, sheets, film, foil and strip, of non-cellular plastics, n.e.c., not reinforced, laminated, supported or similarly combined with other materials (excluding self-adhesive products, floor, wall and ceiling coverings of HS 39.18 and sterile surgical or dental adhesion barriers of CN 3006.10.30)

		ITO			In		24.45.30.50 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
	Orientation films			Polyamidi or carbon			
	Color filter			Pigments, black matrix etc.			
Films				Polymers			
Backlight						Backlight can be produced either by fluorescent tubes or LED	26702430 Parts and accessories of optical microscopes of HS 90.11 26702500 Parts and accessories of optical appliances and instruments of HS 90.13
	Fluorescent tube						27401510 - Fluorescent hot cathode discharge lamps, with double ended cap (excluding ultraviolet lamps) 27401530 - Fluorescent hot cathode discharge lamps (excluding ultraviolet lamps, with double ended cap)
		Phosphorus			Ce,Y,Tb,La,Eu,Gd		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
	LED						26112220 - Semiconductor light emitting diodes (LEDs)
		Semiconductor chip					
			Indium		In		24.45.30.50 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
			Gallium		Ga		24.45.30.50 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
		Luminescent substance					
			Phosphorus		Ce,Y,Tb,La,Eu,Gd		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
Loudspeakers						Some displays may have loudspeakers mounted	

			Magnets				Nd		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
		Electronics							
			Printed circuit board (bare without components)						26121020 - Bare multilayer printed circuit boards 26121050 - Bare printed circuit boards other than multilayer
				Plating					
					Palladium		Pb	Not verry common to use Pd as plating	24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
			Components						
				Capacitors					27905220 - Fixed electrical capacitors, tantalum or aluminium electrolytic (excluding power capacitors) 27905240 - Other fixed electrical capacitors n.e.c. 27905300 - Variable capacitors (including pre-sets)
					Tantalum		Ta		24.45.30.23 Tantalum and articles thereof (excluding waste and scrap), n.e.c.
					Palladium		Pd		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
					Neodynium		Nd		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
				Resistors					27906037 - Fixed electrical resistors for a power handling capacity > 20 W (excluding heating resistors and fixed carbon resistors, composition or film types) 27906035 - Fixed electrical resistors for a power handling capacity <= 20 W (excluding heating resistors and fixed carbon resistors, composition or film types)
					Tantalum		Ta		24.45.30.23 Tantalum and articles thereof (excluding waste and scrap), n.e.c.
					Ruthenium		Ru		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)

				Semiconductors						26112260 - Semiconductor devices (excluding photosensitive semiconductor devices, photovoltaic cells, thyristors, diacs and triacs, transistors, diodes, and light-emitting diodes) 26112180 - Semiconductor thyristors, diacs and triacs 26112120 - Semiconductor diodes
						Gallium		Ga		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
						Germanium		Ge		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium) 20.12.19.50 - Lithium oxide and hydroxide; vanadium oxides and hydroxides; nickel oxides and hydroxides; germanium oxides and zirconium dioxide
						Indium		In		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
						Antimony		Sb		20.12.19.75 Antimony oxides 24.45.30.47 Zirconium and articles thereof (excluding waste and scrap), n.e.c.; antimony and articles thereof (excluding waste and scrap), n.e.c.
					Transistors					26112150 - Transistors, other than photosensitive transistors
						Gallium		Ga		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
						Germanium		Ge		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium) 20.12.19.50 - Lithium oxide and hydroxide; vanadium oxides and hydroxides; nickel oxides and hydroxides; germanium oxides and zirconium dioxide

			Electronic circuit					An integrated circuit, commonly referred to as an IC, is a microscopic array of electronic circuits and components that has been diffused or implanted onto the surface of a single crystal, or chip, of semiconducting material such as silicon. In an integrated circuit, electronic components such as resistors, capacitors, diodes, and transistors are formed directly onto the surface of a silicon crystal.	26113003 - Multichip integrated circuits: processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits 26113006 - Electronic integrated circuits (excluding multichip circuits): processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits 26113023 - Multichip integrated circuits: memories 26113027 - Electronic integrated circuits (excluding multichip circuits): dynamic random–access memories (D–RAMs) 26113034 - Electronic integrated circuits (excluding multichip circuits): static random–access memories (S–RAMs), including cache random–access memories (cache–RAMs) 26113054 - Electronic integrated circuits (excluding multichip circuits): UV erasable, programmable, read only memories (EPROMs) 26113065 - Electronic integrated circuits (excluding multichip circuits): electrically erasable, programmable, read only memories (E^2PROMs), including flash E^2PROMs 26113067 - Electronic integrated circuits (excluding multichip circuits): other memories 26113091 - Other multichip integrated circuits n.e.c. 26113094 - Other electronic integrated circuits n.e.c.
				Capacitors			Ta,Pd,Nd	Look at capasitors	
				Reistors			Ta,Ru	Look at resistors	
				Semiconductors			Ga,Ge,In,Sb	Look at semiconductors	
				Transistors			Ga,Ge	Look at transistors	
			Connectors						
				Copper wire connectors					27331360 - Prefabricated elements for electrical circuits for a voltage <=1kV 27331370 - Connections and contact elements for wires and cables for a voltage <= 1 kV 27331380 - Other apparatus for connections to or in electrical circuit, voltage <= 1000 V
					Palladium plating		Pd		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
					Beryllium copper alloy		Be		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
					Ruthenium alloy		Ru		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)

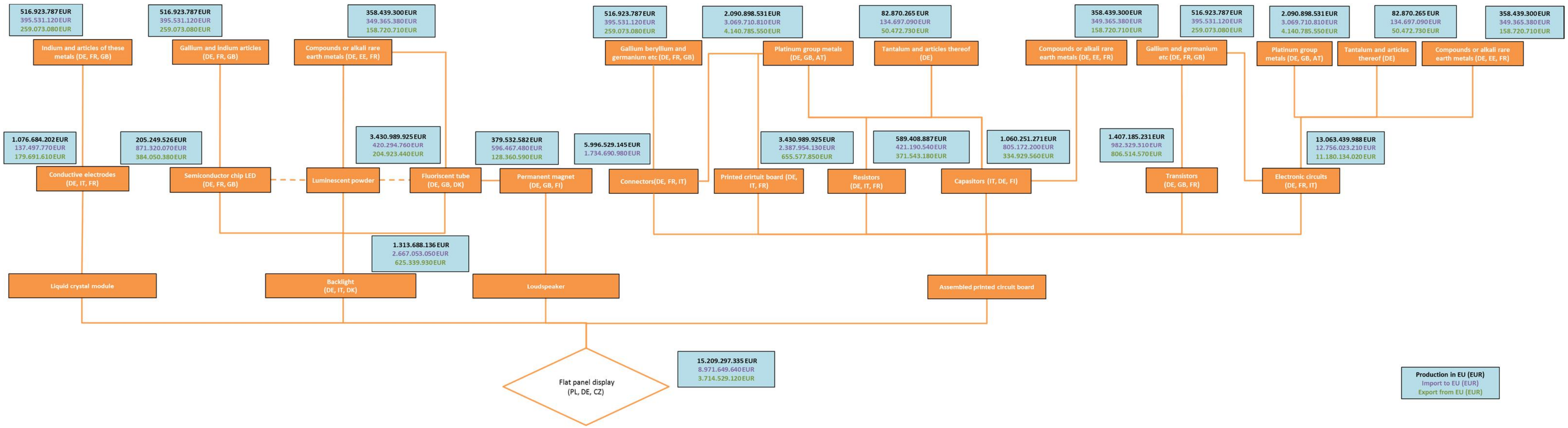

Figure 44: The quantitative supply chain analysis of display based on information from PRODCOM.

Appendix 6 (Washing machine)

The structural composition of washing machine and corresponding PRODCOM groups is presented in Table 36.

Table 36: A structural composition of washing machine application with corresponding PRODCOM groups.

	CRM Content	Comments	Identified PRODCOM categories
Washing machine			27.51.13.00 Cloth washing and drying machine
The Frame			
Electric motor			27.11.24.03 Multi-phase AC motors of an output > 0.75 kW but <= 7.5 kW
Permanent magnet			25.99.29.95 Permanent magnets and articles intended to become permanent magnets, of metal
Iron boron magnets		Not all motors use NdFeB magnets	
NdFeB	Nd, Dy, Pr, Tb	NdFeB magnet contains also small ammount of Dy, Pr and Tb	20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or mixtures of these metals
Electronics		Look at MRI application (Appendix 1)	
Printed circuit board		Look at MRI application (Appendix 1)	
Plating	Pd	Look at MRI application (Appendix 1)	
Components		Look at MRI application (Appendix 1)	
Capacitors	Ta, Pd, Nd	Look at MRI application (Appendix 1)	
Resistors	Ta, Ru	Look at MRI application (Appendix 1)	
Semiconductors	Ga, Ge, In, Sb	Look at MRI application (Appendix 1)	
Transistors	Ga, Ge	Look at MRI application (Appendix 1)	
Integrated circuits		Look at MRI application (Appendix 1)	
Cables			
Connectors	Be, Pd, Ru	Look at MRI application (Appendix 1)	

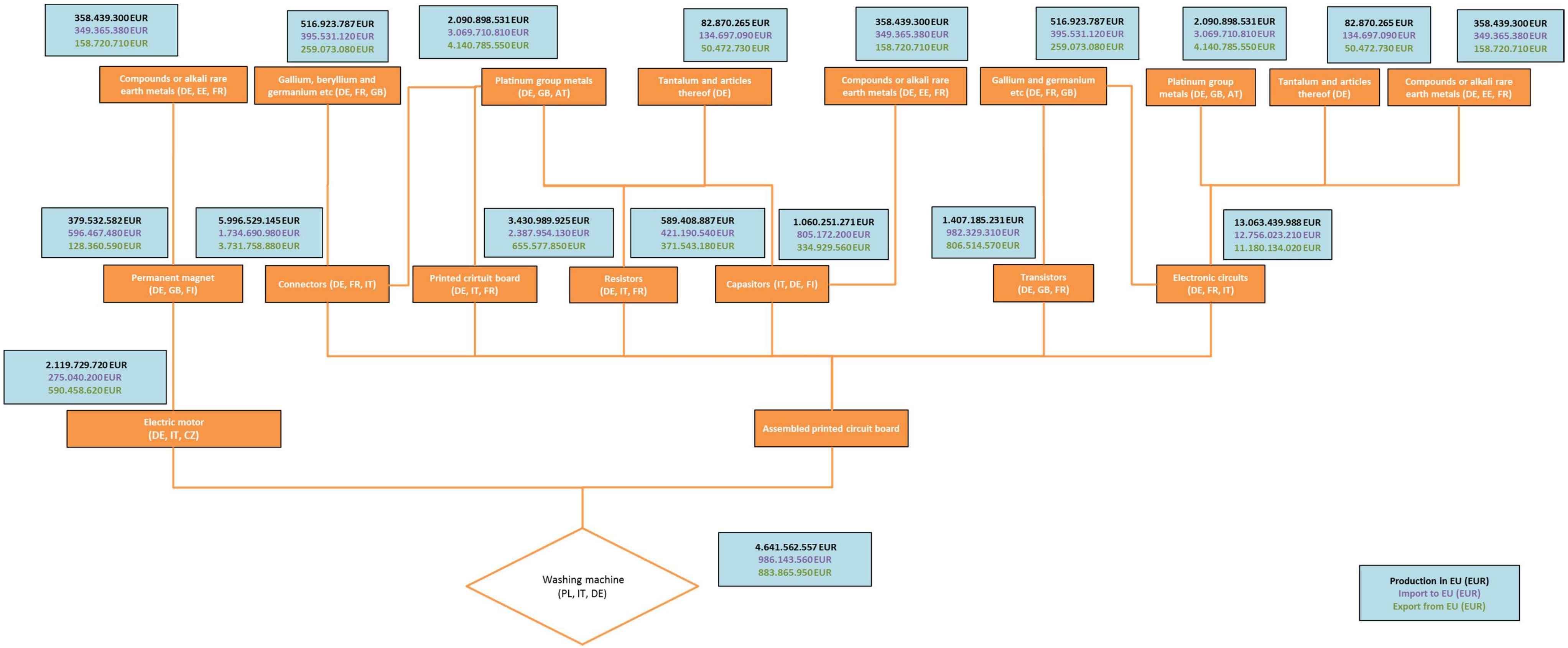

Figure 45: The quantitative supply chain analysis of washing machine based on information from PRODCOM.

Appendix 7 (Assembled PCB)

The structural composition of assembled printed circuit board and corresponding PRODCOM groups is presented in Table 37.

Table 37: A structural composition of assembled printed circuit board with corresponding PRODCOM groups.

	CRM Content	Comments	Identified PRODCOM categories
Assembled printed circuit board			
Printed circuit board			
Printed circuit board (bare without components)			26121020 - Bare multilayer printed circuit boards 26121050 - Bare printed circuit boards other than multilayer
Plating			
Palladium	Pd	Not very common to use Pd as plating	24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
Components			
Capacitors			27905220 - Fixed electrical capacitors, tantalum or aluminium electrolytic (excluding power capacitors) 27905240 - Other fixed electrical capacitors n.e.c. 27905300 - Variable capacitors (including pre-sets)
Tantalum	Ta		24.45.30.23 Tantalum and articles thereof (excluding waste and scrap), n.e.c.
Palladium	Pd		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
Neodynium	Nd		20.13.23.00 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury 20.13.65.00 Compounds of rare-earth metals, of yttrium or of scandium or

								mixtures of these metals
			Resistors					27906037 - Fixed electrical resistors for a power handling capacity > 20 W (excluding heating resistors and fixed carbon resistors, composition or film types) 27906035 - Fixed electrical resistors for a power handling capacity <= 20 W (excluding heating resistors and fixed carbon resistors, composition or film types)
				Tantalum		Ta		24.45.30.23 Tantalum and articles thereof (excluding waste and scrap), n.e.c.
				Ruthenium		Ru		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
			Semiconductors					26112260 - Semiconductor devices (excluding photosensitive semiconductor devices, photovoltaic cells, thyristors, diacs and triacs, transistors, diodes, and light-emitting diodes) 26112180 - Semiconductor thyristors, diacs and triacs 26112120 - Semiconductor diodes
					Gallium	Ga		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
					Germanium	Ge		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium) 20.12.19.50 - Lithium oxide and hydroxide; vanadium oxides and hydroxides; nickel oxides and hydroxides; germanium oxides and zirconium dioxide
					Indium	In		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)
					Antimony	Sb		20.12.19.75 Antimony oxides 24.45.30.47 Zirconium and articles thereof (excluding waste and scrap), n.e.c.; antimony and articles thereof (excluding waste and scrap), n.e.c.
				Transistors				26112150 - Transistors, other than photosensitive transistors
					Gallium	Ga		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)

					Elements	Description	Code
				Germanium	Ge		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium) 20.12.19.50 - Lithium oxide and hydroxide; vanadium oxides and hydroxides; nickel oxides and hydroxides; germanium oxides and zirconium dioxide
Electronic circuit						An integrated circuit, commonly referred to as an IC, is a microscopic array of electronic circuits and components that has been diffused or implanted onto the surface of a single crystal, or chip, of semiconducting material such as silicon. In an integrated circuit, electronic components such as resistors, capacitors, diodes, and transistors are formed directly onto the surface of a silicon crystal.	
	Multichip integrated circuit						
		Processors and controllers					26113003 - Multichip integrated circuits: processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits
			Transistors		Ga, Ge	Look at transistors	
			Semiconductors		Ga, Ge, In, Sb	Look at semiconductors	
			Reistors		Ta, Ru	Look at resistors	
		Memories					26113023 - Multichip integrated circuits: memories
			Transistors		Ga, Ge	Look at transistors	
			Capacitors		Ta, Pd, Nd	Look at capacitors	
		Other multichip circuits				Not elsewhere classified	26113091 - Other multichip integrated circuits n.e.c.
	Electronic integrated circuit (excl. multichip circuits)						
		Processors and controllers				Processors and controllers	26113006 - Electronic integrated circuits (excluding multichip circuits): processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits

Transistors	Ga, Ge	Look at transistors	
Semiconductors	Ga, Ge, In, Sb	Look at semiconductors	
Reistors	Ta, Ru	Look at resistors	
Memories			
D-RAMs	Ga	Dynamic randomaccess memories	26113027 - Electronic integrated circuits (excluding multichip circuits): dynamic random–access memories (D–RAMs)
Capacitor	Ta, Pd, Nd	Look at capacitors	
Transistor	Ga, Ge	Look at transistors	
SRAMs		Static random access memories incl. cache RAMs	26113034 - Electronic integrated circuits (excluding multichip circuits): static random–access memories (S–RAMs), including cache random–access memories (cache–RAMs)
Transistor	Ga, Ge	Look at transistors	
EPROMs		UV erasable, programmable read only memories	26113054 - Electronic integrated circuits (excluding multichip circuits): UV erasable, programmable, read only memories (EPROMs)
Transistors	Ga, Ge		
E^{2}PROMs		Electrically erasable programmable read only memories, incl. flash E^{2}PROMs	26113065 - Electronic integrated circuits (excluding multichip circuits): electrically erasable, programmable, read only memories (E^{2}PROMs), including flash E^{2}PROMs
Transistors	Ga, Ge	Look at transistors	
Other memories			26113067 - Electronic integrated circuits (excluding multichip circuits): other memories
Other electronic integrated circuits		Not elsewhere classified	26113094 - Other electronic integrated circuits n.e.c.
Connectors			
Copper wire connectors			27331360 - Prefabricated elements for electrical circuits for a voltage <=1kV 27331370 - Connections and contact elements for wires and cables for a voltage <= 1 kV 27331380 - Other apparatus for connections to or in electrical circuit, voltage <= 1000 V
Palladium plating	Pd		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)
Beryllium copper alloy	Be		24.45.30.55 - Beryllium, chromium, germanium, vanadium, gallium, hafnium ("celtium"), indium, niobium ("columbium"), rhenium and thallium, and articles of these metals, n.e.c.; waste and scrap of these metals (excluding of beryllium, chromium and thallium)

			Ruthenium alloy	Ru		24.41.30.30 Platinum, palladium, rhodium, iridium, osmium and ruthenium, unwrought or in powder form 24.41.30.50 Platinum, palladium, rhodium, iridium, osmium and ruthenium, in semi-manufactured forms (excluding unwrought or in powder form)

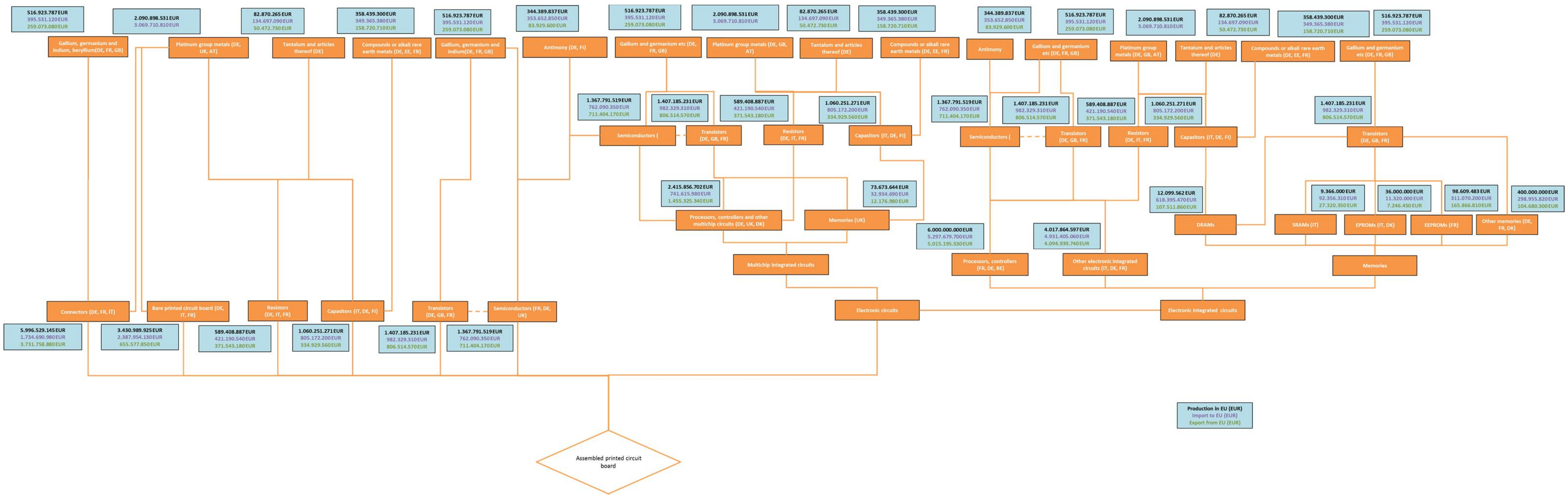

Figure 46: The quantitative supply chain analysis of assembled printed circuit board based on information from PRODCOM.